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5.4 Conclusions

5.4.1 Background

Fundamentally, we wish to answer the simple question: Does biodiversity matter in the functioning of ecological systems? This question should be addressed with respect to the four major principles introduced in Section 5.0: (1) the levels of biological and ecological organization and their interactions, (2) the numbers of different biological units within each level, (3) the influence and degree of similarity in the traits or roles that biological and ecological units within each level play, and (4) the spatial configuration of the units within any level. We have thus summarized the conclusions of the chapters in Section 5 with respect to these four principles. We then proceed with a synthesis of these conclusions with respect to the influence of human actions and implications for management. The summary and synthesis take the form of several simple questions.

5.4.2 What are the influences of genetic diversity on ecosystem functioning?

Ehrlich (5.1) and Templeton (5.2.1) both point out that intraspecific genetic variation can be, and has been, exploited to change quantitative aspects of ecosystem functioning, e.g. by increasing crop yields. In addition, intraspecific genetic variability confers some adaptive capability to those species, and thus increases the possibility that their functional roles can continue to be expressed in ecosystems that are undergoing environmental variability or stress. There is very little information on whether the genetic similarity of populations influences ecosystem functioning. Templeton (5.2.1) points out that the phenomenon of local adaptation of populations to their environment is well known, and thus the spatial configuration of genetic variability might be important. Reintroduction of species to areas from which they have been lost is generally most successful if the reintroduced individuals are from populations that originated close to the original area. It is not unreasonable to suppose that there are ramifications of these observations for ecosystem functioning, but direct experimental evidence or observations are lacking.

5.4.3 What are the influences of species diversity in ecosystem functioning?

In many cases, species clearly matter. This is primarily because the species plays an important and unique role in its ecosystem. Removal or addition of the species results in a dramatic and obvious change in the other species in the ecosystem or in a key ecosystem process. The evidence for this conclusion is compelling; the number of examples is increasing as more systems are examined; and these keystone species (Chapin *et al.*, 5.2.2) have been reported from a wide range of ecosystem types. However, in spite of the widespread existence of the phenomenon, no species characteristics have emerged that allow prediction of which species will play keystone roles. In fact, some small or cryptic species have been found to play a keystone role.

In many other cases, however, there appears to be substantial overlap among species with respect to their functional roles. Their removal or addition appears to have little demonstrable effect either on other species or on an ecosystem process. Other species compensate for the absence of the target species, at least in the short term. However, it is not known with certainty if all functions of the species in question are compensated for (in fact, it is rarely understood what the full range of functions is for each species). For this reason, it is probably inappropriate to say that species are 'redundant'.

Ecosystems with greater overlap among species with respect to any particular process will be more resistant to change than otherwise comparable systems characterized by little compensatory potential. This stability is predicted to be a direct result of the fact that species that overlap with respect to a particular function probably differ with respect to their responses to environmental changes such as temperature, salinity, ultraviolet radiation (UV-B), or explosure to toxic compounds. Compensatory overlap is thus suggested to provide 'insurance' in the sense that key functions are more likely to continue despite changes that result in the loss of some species. There is some evidence for this prediction, but it is a very difficult phenomenon to demonstrate. There is no evidence that contradicts the predictions. This is an area where further research is needed.

The above conclusions focus on particular traits of species and the extent to which the traits are unique to a species or not. A separate question of importance is whether the number of species *per se*, apart from their specific traits, has a strong influence on ecosystem properties. The number of species in an ecosystem is functionally important, independent of the traits of the species, for two reasons: (1) more species generally increase the rate or efficiency of resource capture under steady-state conditions, and (2) more species provide insurance against large changes in ecosystem processes in response to disturbance or environmental change (Chapin *et al.*, 5.2.2).

The spatial structure of species populations within ecosystems has influences on their interactions, their diversity and abundance, and therefore on ecosystem-level processes (Harrison, 5.2.3). Changes in spatial structure, especially fragmentation of habitats, act differentially on different kinds of organisms, depending in part on body size, trophic level, life-history characteristics and successional stage. Fragmentation reduces the diversity of native species in their natural habitats and the types of species most likely to be lost are those with the highest rates of local extinction on small habitat patches (e.g. top predators and other species with large body sizes and large area requirements). Also likely to be lost are species with lower abilities to disperse and colonize habitat patches. Species likely to survive fragmentation will be those best adapted to patchy and frequently disturbed environments, especially early successional and easily dispersed species.

Fragmentation is thus expected to result in ecosystems dominated by 'weedy' species characterized by short life-span, rapid growth rate, and high reproductive and dispersal capacity. This, in turn, is expected to result in numerous ecosystem-level consequences: faster turnover and leakier systems with respect to nutrients, nitrogen, and carbon; higher litter quality and therefore faster decomposition rates; simpler spatial structure; less overall protection from herbivory; and different kinds of chemical defences against herbivory, tending to low molecular weight compounds.

Thus, the assessment is revealing that in many cases 'species matter' in a fashion that can be demonstrated; in others, species appear to be sufficiently similar to other species with respect to their functional roles that their loss should have no immediate consequences, but unequivocal demonstration that they will or will not 'matter' over a longer period of time is difficult and unlikely to occur. This does not mean that every single species matters in every single situation. There are certainly examples where species have been lost and there has been no demonstrable change to the ecosystem's functioning. It is difficult to say, however, that no change occurred; the evidence available does suggest that there was no catastrophic change.

5.4.4 What are the influences of landscape diversity on ecosystem functioning?

At a landscape or regional scale, the key processes to understand are those that regulate the movement of materials (e.g. nutrients, water, trace gases, etc.), energy fluxes, and dispersal of organisms among the constituent ecosystems, and between the ecosystems and the atmosphere and hydrosphere (Burke and Lauenroth, 5.2.4). The number of different types of ecosystems on a landscape has obvious effects on the total functioning of the landscape. Those ecosystems that cover large areas obviously have important roles; however, some ecosystems on a landscape have functional importance out of proportion to their abundance (Burke and Lauenroth, 5.2.4). This is true of riparian areas and wetlands, particularly in respect of their capabilities to purify water before it reaches streams and rivers, and also for marine systems such as coral reefs, mangroves and kelp forests.

Because of climatic, topographic and geological variation; historical differences; and disturbance frequency, severity and extent (Pickett, 5.3.1; Burke and Lauenroth, 5.2.4), the arrangement of ecosystems on the landscape can be extremely complex, and this complexity affects the total functioning of the landscape. Many of the transfers across landscapes are the result of directional processes, such as wind and water flow, and therefore the total effect of the processes in a region may depend critically on the actual spatial arrangement of the ecosystems, and how that array is orientated with respect to these abiotic factors. The fragmentation of habitat associated with human activities can alter landscape/regional diversity by affecting the spatial patterns of ecosystems on the landscape, by fragmenting the landscape, in effect creating new, disturbed areas, and/or by decreasing the total area of different ecosystems on the landscape. Each of these effects may have characteristic results for different types of species, and thus for ecosystem processes. For example, the spatial pattern of the fragmentation results in the provision of dispersal corridors for some organisms, but reductions in available habitat and opportunities for dispersal and migration for others, and can have a great effect both on overall levels of biodiversity and on ecosystem functioning across the landscape.

5.4.5 What are the human influences on ecosystem functioning?

Human-induced changes in biodiversity are characterized by their increased frequency (rate of change), severity (magnitude of change), and increased spatial extent (Sala, 5.3.2). At a local scale, human activities can have negative (local population eradication), neutral (sustainable harvesting), or even positive (e.g. increase in the number of landscape units) effects on biodiversity. When viewed at a global scale, though, human activities reduce biodiversity at genetic and species levels, and species' extinctions are completely irreversible. In addition, human activites can create environmental changes for which biota are not at all adapted, for example increased surface UV-B flux due to reduction in stratospheric ozone, or the proliferation of novel, but extremely toxic compounds in the environment.

Extractive activities, such as agriculture and forestry, tend to increase the fluxes of materials in ecosystems across a landscape, often leading to increased losses of nutrients, increased surface water flow, increased sedimentation in streams and rivers, and long-term reductions in soil carbon and soil fertility. These activities clearly affect landscape functioning through their effect on the diversity of ecosystems within a landscape. Other human activities, such as the construction of dams for water control, have very different effects at landscape scale, often resulting in the concentration and immobilization of nutrients and sediment in particular parts of the landscape. Still others, such as fire control in forests, have the effect of dramatically changing the disturbance regime, resulting in widespread changes in landscape functioning.

5.4.6 *What are the management implications for goods and services?*

To manage and exploit the environment effectively and sustainably, scientific information needs to be translated into management plans and actions. However, there is great difficulty in managing to provide goods and services simultaneously while maintaining diversity at prudent, sustainable levels. Several important principles can be used to guide the implications for management: (1) practical constraints on feasibility, environmental acceptability and economic desirability must be clearly understood; (2) a goal-orientated approach must be applied that recognizes that there are always multiple objectives in any management scenario; (3) an iterative process, analogous to that of adaptive management in forestry, should be employed in order to integrate the knowledge gained from earlier management decisions into a continually improving management scheme; and (4) when uncertainty about the resource base or the knowledge base is predominant, the precautionary principle should be employed, thus avoiding whenever possible decisions that close off future options.

5.4.7 *Summary*

Section 5 has laid out in broad detail the important concepts governing the study of the relationships between biodiversity and ecosystem functioning. The importance of considering biodiversity at multiple levels of organization is emphasized, as is the degree of influence and similarity in traits, and the spatial arrangement of biological units within any level of organization. Redundancy of function of species within ecosystems and ecosystems within landscapes cannot be assumed: indeed, some species and ecosystems have unique functional roles that are significant out of all proportion to their abundance. The main consequence of diversity at all levels seems to lie in the degree of adaptive insurance it provides for the maintenance of ecosystem processes against environmental variation and/or stress.

The human influences on biodiversity and ecosystem functioning have largely taken the form of rapid, large, and frequent changes in land and resource use, increased frequency of biotic invasions, reductions in species numbers, creation of novel stresses, and the potential for change in the climate system. Although disturbance is a critical element controlling the composition and functioning of ecosystems, human influences have increased its pace and extent well beyond previously known levels. The major implications for the continued provision of ecological goods and services are to create and use management strategies in an adaptive fashion, to ensure that sufficient resources are maintained in the system to provide resilience, and to be cautious about making potentially irreversible decisions.