Global change and ecological complexity: an international research agenda

There is growing concern over the apparently accelerating loss of the world's biodiversity. While much of this concern has focused on the origins, monitoring, conservation and sustainable use of biodiversity, there is increasing interest in the functional role of biodiversity. Building on earlier SCOPE (Scientific Committee of Problems of the Environment) and UNEP (United Nations Environment Programme) studies on this issue, the Global Change and Terrestrial Ecosystems (GCTE) Core Project of the International Geosphere–Biosphere Programme (IGBP) is establishing an international research programme to (1) determine the relationship between ecological complexity and ecosystem functioning, (2) determine how global change affects this relationship, and (3) elucidate some important consequences of changes in ecological complexity and ecosystem functioning for policy and resource management.

The term 'ecological complexity' represents biological diversity in a broad sense, including not only species diversity but diversity of ecosystems and landscapes, as well as genetic diversity within species. In addition, ecological complexity involves the diversity of trophic pathways and interactions, that is, the connectivity of ecosystems. 'Ecosystem functioning' refers to key ecosystem processes, such as primary productivity, nutrient cycling and water transport.

Proposed models of the relationship between ecological complexity and ecosystem functioning range from a model in which each species is assumed to be unique, to one in which most species are considered redundant. Most models begin with 'species richness', that is, the number of species in the system, but then go on to consider in more detail the 'per capita impact' of species on ecosystem processes. However, most of these models are very new, and either have been tested at only a single place within a single ecosystem, or with poorly replicated experimental designs, or they have not yet been tested.

The GCTE research agenda is built around a number of key elements. First, a series of experiments and observational studies is being initiated. One of the most exciting involves the construction of synthetic communities growing under natural field conditions. The manipulated variable in these communities is the diversity of the component organisms, and the effects on ecosystem functioning will be studied.

Other approaches to studying the relationship between ecological complexity and ecosystem functioning are also planned. These include: (1) construction of synthetic communities in laboratory conditions; (2) field manipulative experiments in which species or functional types are added to or deleted from existing ecosystems; (3) use of existing diversity gradients; and (4) opportunistic experiments in which systems are manipulated for other purposes, for example, a comparison of selectively logged forest stands with adjacent species-rich ones.

The second element focuses on the landscape scale, where complexity is determined by the number of patches, their characteristics, their size and shape, and their connectivity or pattern. The critical questions are: When does landscape pattern matter? When can we simply add up contributions from the individual units, and when can we not? How do these relationships vary with the function of interest? How will global change affect landscape complexity, and in turn ecosystem functioning? Two major types of process will be considered: (1) transfer of matter and energy across landscapes and between the land surface and the atmosphere, and (2) movement of organisms across landscapes, including such phenomena as migration and the viability of isolated populations.

The third element of the GCTE strategy centres on the global change aspect – rapid changes in global environment and land use, loss of biodiversity and the introduction of exotic species. A coordinated international set of studies to tackle this difficult issue is proposed, with most based on patch-scale experiments involving factorial combinations of altered climate, atmospheric inputs and changed land use.

Some land-use change manipulations are relatively easy, such as grazing intensity on herbaceous systems, while others involving, for example, harvesting of woody species are more difficult. The list of atmospheric/climatic candidates is large (e.g. carbon dioxide, ozone, UV-B, temperature, rainfall) and some manipulations, such as carbon dioxide elevation, are expensive. This suggests that a two- or three-tier approach may be necessary in which manipulations of 'expensive' variables are attempted at only a few sites while others are included across many sites.

A key element that interacts with the other components of the programme is based on modelling the relationship between ecological complexity and ecosystem functioning, and the impacts of global change on it. One approach involves the construction of models based on theory, which can be used (1) to test hypotheses relating complexity to functioning, (2) to understand the mechanisms that determine or drive the complexity/functioning relationship, and (3) to understand general patterns in the relationship that might emerge across systems or across perturbations and climatic forcings. Another type of simulation tool is based on the development of data-driven models that are intimately connected with experimental and observational studies, and are designed to describe and explain experimental results.

A final, critical element of the GCTE programme centres on the socioeconomic consequences of changes in ecological complexity. An early product of this component of the programme will be the construction of a set of scenarios of changes in ecological complexity. These scenarios will parallel those on atmospheric composition, climate and land use, and will encompass many important aspects of changes in ecological complexity, such as rates of extinction, biological invasions and loss of connectivity through habitat fragmentation. An interesting feature of the scenarios will be the capability to identify, around the world, ecosystems that are vulnerable from the functioning standpoint, that is, areas where relatively small changes in ecological complexity may lead to large changes in ecosystem functioning, and also from the conservation perspective, that is, areas that may undergo large changes and/or are particularly rich in diversity.

A particularly important implication of changes in ecological complexity relates to land-use planning and resource management. Biodiversity conservation is an increasingly important issue, and sound scientific backing is needed for strategies to deal with rapid environmental change, such as landscape fragmentation and climatic change. Management plans will need to consider not only protected areas, but also the entire matrix of land cover units of varying ecological, economic and cultural characteristics.

The GCTE research agenda is clearly formidable, but offers a unique opportunity for collaboration between the global change and biodiversity research communities.

W.L. Steffen

GCTE Core Project Office, CSIRO Division of Wildlife & Ecology, PO Box 84, Lyneham, ACT 2602, Australia

F.S. Chapin III

Dept of Integrative Biology, University of California, Berkeley, CA 94720, USA

O.E. Sala

Dept of Ecology, Faculty of Agronomy, University of Buenos Aires, Av. San Martin 4453, Buenos Aires, Argentina

  PII: S0169-5347(96)20030-8