Biodiversity in a changing world: land use and other effects on landscape and regional diversity

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Summary of lecture

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This lecture focused on the effects of global change on biodiversity. Some important concepts and methodologies to project future diversity responses to global change were presented and discussed.

Effects of Global change on biodiversity

Already profound effects can be observed of global change on the composition and functioning of ecosystems. For instance as a result of climate change, distributions of species and timings of life events (e.g. phenology) are changing. A global meta-analysis by Parmesan and Yohe (2003) showed that the range boundaries of species distributions shifted on average 6.1 km per decade towards the poles (or 6.1 m upwards in altitude) and that phenological processes started 2.3 days earlier per decade. Examples from the Alps showed increased diversity on higher summits and invading non-native species from warmer climates.

Studies that compared the effects of climate change with effects of land-use indicate that land-use is the major and most immediate factor affecting ecosystems. For instance a ranking of drivers of change of biodiversity for terrestrial ecosystems by Sala et al. (2000), showed that land-use will probably have the strongest effect, followed by climate change, nitrogen deposition, biotic exchange and carbon dioxide concentrations. Only in arctic, alpine and boreal systems the effect of climate was stronger than that of land-use. Mediterranean climate and grassland ecosystems are expected to experience the largest relative changes in biodiversity because these systems will be substantially influenced by all drivers (Sala et al. 2000). Northern temperate ecosystems will probably experience least effects, mainly because major land-use changes have already occurred.

Human population density is a major driver for land-use changes. People transform natural landscapes for agricultural, urban and infrastructural purposes, leading to disturbed and fragment landscapes. Increasing fragmentation of natural landscapes will impede the possibilities of organisms to respond to climate change (e.g. Warren et al. 2001).In 1995 20% of the world population was living in 25 biodiversity hotspots (12% of Earth's terrestrial surface) (Cincotta et al. 2000). At the same time population growth rates in these hotspots were substantially higher (1.8 % yr^{-1}) than that of the whole world (1.3 % yr^{-1}) and just above that of developing countries (1.6 % yr^{-1}) (Cincotta et al. 2000). These demographic trends in the biodiversity hotspots and tropical wilderness areas indicate that in the future habitats dominated by humans will further expand in these biologically most divers regions.

Methodologies to project future diversity response to global change

To study future effects of global change on diversity, projections of diversity responses to these changes need to be made. Three methodologies were discussed: 1) Niche based modelling, 2) statistical models of habitat change and species area relationships and 3) modelling of species distributions based on plant traits.

Niche based modelling
Niche based models can be used to predict future geographic distributions of species under different climate change scenarios. Based on current occurrences of a species in geographic space (i.e. edaphic, climatic and environmental conditions the species occurs in, e.g. water availability, amount of winter precipitation and degree days) its niche in ecological dimensions can be modelled. For each of the environmental variables response curves with probability of presence under different conditions need to be developed. With these response curves and information on future climatic conditions the future geographic ranges of a species can be predicted.

Like all models, also niche based models depend on a number of primary assumptions. It is assumed that i) data on current species distributions and environmental variables are adequate (the species has been found where it should be), ii) the selected environmental variables do indeed control the geographic distribution, iii) the used statistical methods detect correct relationships, iv) climate and land-use will change as predicted, and v) under changed climatic conditions the same response curves will hold (no plasticity and genetic adaptation).

Examples for several plant species showed that responses to global change differ widely, depending on the environmental preferences of the species. Individual species responses to projected climate changes should therefore be aggregated to determine the future impact of global change on species richness. An analysis of relative sensitivity of plant diversity to climate change in 2080 by ATEAM researchers showed that mountain and Mediterranean regions are most threatened, while in Scandinavian areas the number of species is expected to increase.

Some disadvantages of niche based models are i) that they cannot be validated; ii) it is difficult to distinguish the separate effects of land-use and climate, iii) they assume free movement (migration) of species, and iv) species from other continents are not included.

Statistical models on habitat change and species-area relationships

Effects of land-use change on biodiversity can also be analysed by combining species-area curves (statistical relationship between size of an area and number of species on that area) with projected loss of habitat. It assumes that loss of habitat area will result in the loss of a certain amount of species as determined by the species-area relationship. With this method it is also possible to include effects of for instance climate change and N-deposition.

This was also the method applied in the Millennium Ecosystem Assessment projections. These projections showed again that land-use change (expansion of agriculture) is the most important factor for future loss of species in warm mixed forests, with only a small additional effect found by including climate change or N-deposition. However for tundra ecosystems it was found that climate change is the most important factor, while for boreal forests hardly any effect was found.

Modelling species distributions based on plant traits

To bring some biology into the models, plant functional traits (PFT) were introduced. The use of these PFTs is a tool to reduce the complexity of life, taking a functional rather than a taxonomic perspective. In this approach, species or populations are grouped based on similar responses to environmental changes and similar effects on ecosystem functioning that are the result of shared characteristics. Functional traits can be determined on different functional levels, e.g. morphology, eco-physiology, demography or biochemistry. Traits (e.g. dispersal, growth rate, photosynthetic capacity) can be used as indicators for plant function (e.g. regeneration, colonisation, migration, establishment and resource capture). Many plant traits relating to the functioning of plants can be described, but in general especially those traits that can be easily determined in the field for large numbers of species are preferred. These latter (soft) traits can be used as proxies for traits that are more complex and difficult to measure like photosynthetic capacity. For instance the morphological traits leaf mass area and leaf nitrogen content are very good predictors of photosynthetic capacity (Wright et al. 2004).

Analyses of the effects of traits on species distributions and of trait responses to climate changes then can be used to determine responses of plant to environmental changes. This approach can also be used to determine changes in traits within communities in response to climate and land-use change. For instance changes in land use and climate will have an effect on the ratio of dry to fresh mass of leaves (LDMC), or in other words, the density of its structural tissue. Species at colder sites in general have higher LDMC (denser leaves) than species from warmer climates (prevalence of annual species with lower LDMC at warmer sites). At the same time an increase in LDMC was found in response to extensification of land-use (promotion of species that conserve mineral resources, i.e. have sturdy and dense leaves). Eventually changes of traits within communities may have profound effects of ecosystem functioning and thus is likely to affect the delivery of ecosystem services.

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