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Nature restoration in a world of climate change: identifying scale issues and key landscape connections.

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Abstract

In landscapes around the world humans have fragmented and destroyed natural areas. For the conservation of nature it is now often necessary to restore the previously natural areas in the landscape. Nature restoration measures are, however, planned usually at small, local scales. In contrast to the size of restoration measures, conservation biology generally promotes restoration and protection of large areas. Our aim is to point out that restoration should not target small, local areas or indefinite large areas, but those landscape elements that together support the survival of the populations, species, ecosystems or ecosystem functions of interest. We propose to call a combination of these landscape elements and their hydrogeological and biotic connections an operational landscape unit (OLU).

Restoration of OLUs has the following benefits: Connections between natural landscape elements are restored, thereby restoring flows of biota and water. This restores gene flow, (re-)colonization potential, regional species dynamics, migration, gradients in biotic and abiotic conditions, and ecosystem functioning. The size and connectivity of the restored area in the OLU reduces the impact of the surrounding man-modified landscape on the area in the OLU. This diminishes or prevents continuing deterioration of the areas, saving labour and financial resources on the long term. It also increases the robustness of the areas under changing conditions. Especially in the light of climate change, connectivity between landscape elements and robustness of natural areas are important.

OLUs are identified at the landscape scale. The scale of the OLU and the landscape elements required in it should be derived from ecological information on the population, species, ecosystem or ecosystem function to be conserved. Recent progress in spatial ecology, spatial modelling and GIS applications has made such information available, and will continue to do so. Especially in the fields of habitat connectivity and surface and ground water flows progress has been made. GIS applications allow combination and visualisation of spatial information. For example, multiple maps of OLUs can be overlayed for a given landscape to identify areas of highest restoration priority.

Keywords Biodiversity, climate change, conservation, ecosystem functions, global change, landscape ecology, operational landscape unit, restoration

Introduction

Nature conservation aims to preserve the worlds' species diversity and ecosystem functions in an increasingly man-modified setting. Traditionally, nature conservation focussed on the protection of selected species, mainly large vertebrate species because of their popularity. Over the past decades, the focus on species protection widened and conservation shifted to the preservation of larger or smaller areas of rare species habitat, high biodiversity or valuable ecosystem functioning. This approach evolved to include spatial considerations in nature conservation strategies, aimed first predominantly at preservation of large areas and later also at preservation of networks of habitat areas, the 'ecological networks'. In the last decade this focus became so strong that Schwartz (1999) noted that 'it has been posited that the era of species conservation is over and that ecosystems integrated within landscapes will be the conservation unit of the future'.

The need for this approach to nature conservation in densely populated regions arises from the increasing degree of landscape fragmentation, because of progressive urbanization and associated intensification of agricultural activities. This fragmentation has been shown to have dramatic consequences for biodiversity and for environmental quality. A first consequence of landscape fragmentation is the transformation of large natural landscape patches connected by wide, continuous corridors into a large number of small patches, many of which are not connected to each other. This development is a combination of loss of area because of habitat destruction, e.g. for housing or agriculture, and loss of connectivity because of destruction of corridors or the construction of barriers such as roads. As predicted by the ecological theory on island biogeography, the small patch size leads to high extinction and the high degree of isolation to low colonization, resulting in a severe loss of species richness of patches and of the landscape as a whole.

A second consequence of agricultural intensification is the drastic change in the hydrological functioning of catchments. Measures to drain agricultural land have lead to lower groundwater tables, loss of groundwater discharge in (semi-)natural landscape patches, straightening of lower-order streams, dampening of stream water level fluctuations, loss of floodplain habitat, loss of meandering as a natural stream habitat process and a deterioration of stream water quality. These changes have lead to drastic changes in ecosystem functioning, often deteriorating (the diversity of) habitat site conditions all across the landscape, even in protected reserves with appropriate internal management. It is evident that these landscape-scale modifications, including hydrological measures and land amelioration such as flattening of microtopography, have resulted in additional losses of biodiversity, which have probably been just as severe as those caused by fragmentation per se.

Although both major consequences of fragmentation have been recognized and documented, there has so far been no conceptual framework which considers them in combination. The issue of patch size and connectivity has been addressed in metapopulation theory, which has been shown to adequately predict the consequences of fragmentation for animal species with a reasonable ability for dispersal (e.g., birds, mammals, flying insects, (Hanski 1999). The issue of the importance of the hydrological functioning of catchments for biodiversity and water quality has been recognized mostly in studies emphasizing vegetation or buffer zone functioning. The concept of homogeneous Hydrogeomorphic Units within catchments (HGMU) (Maltby *et al.* 1994; Maltby *et al.* 1996). and the concept of Hydrogeologic Setting of wetlands (HGS) (Godwin *et al.* 2002; Bedford & Godwin 2003) have been proposed to emphasize the need for delineating functional units in the landscape, and the relation between vegetation and water and soil chemistry, respectively. These concepts do not address connectivity, either hydrological or biotic, but particularly the HGS concept does recognize the importance of intact hydrogeological processes for plant diversity. None of these approaches specifically focuses on restoration.

In this paper, we propose the Operational Landscape Unit concept, which combines biotic and hydrological connectivity to analyze the best options for restoration of ecosystem functioning and plant biodiversity in fragmented landscapes. This framework enables resource managers to select the best locations for restoring biodiversity within a landscape or catchment, to identify the extent of the total area needed for restoration of target species and communities and to determine which measures need to be taken to restore biotic and hydrological connections. Our aim is to suggest how the recently much increased ecological knowledge on the spatial requirements of species and the spatial distributions and connections of ecosystem processes can be combined to develop more effective regional conservation strategies. These strategies aim at the preservation and, where necessary, restoration of those landscape elements that target species and ecosystem functions required to operate successfully. Preservation and restoration of just a carefully selected set of landscape elements in an area will be less costly but equally effective, if not more effective, than that of a large area whose main quality is that it is 'large'. It will result in effective ecological networks. And it will be more effective, and on the long-term potentially less costly, than the preservation and restoration of small areas that lie isolated within the landscape. To do this successfully, ecological knowledge from population biology and ecosystem science has to be combined.

The OLU concept combines biotic and abiotic processes and connectivity at the landscape scale to analyze the best options for preservation and restoration. GIS allows for the overlaying of maps containing spatial information on individual species, ecosystem functions and hydrological flows and allows adding information on as many species and functions as required. We stress that it is crucial that regional conservation strategies are spatially coherent based on the spatial scales of the ecological, hydrological and biogeochemical processes that are relevant to preserving the abiotic conditions and flora and fauna of the ecosystem under consideration, and should consider habitat connectivity for key species as well as abiotic connections between ecosystems in the landscape.

Importance of spatial issues beyond individual sites

The traditional spatial scale of preservation and restoration measures is the scale of an individual habitat patch or part of such a patch (*e.g.*, 100 m of the reach of a stream, a forest patch in a deforested landscape, a moorland pool). It is certainly better to preserve and restore what is possible than do nothing at all, and conservation of individual habitat patches or their parts is sometimes highly successful (Schwartz 1999). However, such a small-scale approach to preservation has well-recognized disadvantages. Small sites contain only small, therefore vulnerable populations. Small sites may not support full functionality of an ecosystem function. Small sites are vulnerable to influences from their surroundings and may suffer from edge effects. Small sites may be isolated and consequently may experience population genetic problems as well as lack of colonization after a population has gone extinct.

It is not surprising that the need for nature restoration, in addition to conservation of still existing nature, has primarily been recognized in strongly fragmented and otherwise degraded landscapes. Here, the loss of species can only be turned around by increasing patch size and patch connectivity. At the same time, in these same landscapes the habitat conditions of remaining patches often need to be improved in order to match the requirements of species-rich plant communities containing rare species. Increasing the size and habitat quality of existing nature reserve patches is a strategy with relatively good prospects for enhancing biodiversity conservation, because the species are already there as adult, juvenile or diaspore. Habitat quality improvement can be achieved by measures within the patch, such as water level manipulations by small weirs or even pumps. However, the long-term species richness of patches will be better guaranteed by a strategy that takes into account the spatial relationships in the larger landscape or catchment context. This is true for the biotic connections through dispersal of plant diaspores between patches via wind, water or animals, as well as for hydrological connections involving groundwater discharge/recharge phenomena, water level fluctuations, sedimentation and meandering. Hence, recognition of ecological processes at different scales is of paramount importance for determining successful restoration strategies in catchments subject to fragmentation.

Ecological networks may include large areas, but usually do not. Instead of large areas, the lack of colonization or flow of organisms or particles between sites within the network is hopefully secured through connectivity between the sites in the network. This connectivity may be enhanced by corridors, which sometimes consist of very long and narrow (down to only a few m wide) strips between larger sites. Effectiveness of such corridors is often not known, and if known usually only for a few animal species, usually the larger invertebrates. Effectiveness for plants is often assumed, but has never been tested.

In population biology, the processes that require a greater scale than the scale of (a) single site(s) are biological processes, mainly the dispersal of organisms. The main reason for spatial conservation strategies at larger spatial scales than particular local sites, is that sites may be too small for animals with large home ranges, or animals that migrate seasonally or during juvenile stages. Also, exchange of individuals between sites may be required to prevent inbreeding depression or loss of genetic variation through genetic fixation or genetic drift. Also, spatial scales may determine species interactions such as predator-prey dynamics or escape from natural enemies. The relevant spatial scales in the landscape are determined by all target species, not just popular species such as large vertebrates. The larger the number of target species, the larger the variety of dispersal mechanisms and dispersal capabilities, and the larger the variety of relevant spatial scales.

The abiotic processes shaping species' habitats, that operate at a larger scale than the scale of a single site are mainly fluxes of ground and surface water and dissolved substances, as well as erosion-sedimentation phenomena. Groundwater flows have a lateral component and flow in the landscape from groundwater recharge areas at higher elevations towards groundwater discharge areas at lower elevations. The groundwater recharge areas are often the prime areas for human land uses such as urban development, agriculture and industry, but they also have (semi-)natural patches such as woodlands, heathlands and species-rich grasslands. The groundwater discharge areas often have more (semi-)natural patches, e.g. moist grasslands, depressional wetlands, floodplains or streams. In many stream catchments, the hydrology has been drastically altered. The main goal was often to quickly drain water from precipitation from the major part of the catchment and bypass the normal routes through groundwater recharge and (sub)surface runoff. Drainage systems carry the water almost immediately to the streams, which themselves have been straightened and widened to enable a quick discharge to larger river systems. These modifications of natural large-scale processes have also strongly impacted plant diversity in individual sites.

Recognition of ecological processes at different scales in a spatial landscape context is often of paramount importance for determining successful restoration strategies. We make a plea for a proper analysis of scale issues in designs for nature management and restoration measures to increase ecosystem resilience/ robustness (ecosystem independence from human intervention), especially in the light of climate change. Systems need to be as independent as possible of intensive and costly human management for long-term conservation. To find the right spatial extent for nature restoration and management, we propose to base conservation strategies on knowledge originating from population ecology, hydrogeology and systems ecology, and we propose using Operational Landscape Units as a tool.

Operational landscape units

We propose to summarize information from population biology and ecosystem science on the ecologically relevant scales of species and ecosystems processes in the Operational Landscape Unit (OLU) concept. We define OLU's as '*combinations of adjacent landscape patches with* *their hydrogeological and biotic connections*'. An example of an OLU is (from high to low elevation) a combination of flat or sloping patches with groundwater recharge, the patches with groundwater discharge to which they are connected through local groundwater flow or overland run-off, the floodplain or stream bank patches and the stream itself. OLU's in a catchment may be mutually connected through surface water flow in the stream or through regional groundwater flow. An important notion is that the connections that characterize OLU's are often disrupted in fragmented landscapes: groundwater recharge areas are being drained so that water short-circuits to the stream and groundwater discharge is strongly diminished; streams have been straightened to maximize hydraulic flow rates; floodplains have strongly decreased because of diking or stream water level control. This has also a direct bearing on water-dispersed seeds, and, through effects on fauna dispersal, on animal-dispersed seeds. As we will explain below, the OLU concept can be a valuable tool to analyze the scales on which key landscape connections for plant species richness operate, and to define the best strategy for restoration and conservation of botanical diversity in stream catchments.

By approaching spatial conservation strategies using spatial landscape units, a spatial overview of the situation is created. For the combination of all relevant spatial scales in a GIS, maps of the OLUs need to be created. These maps each represent the minimal combination of landscape elements that are required for regional survival of a species or self-sustaining ecosystem functioning creating target conditions in the reserves. For a regional conservation strategy, OLUs of all relevant species and ecosystem processes can be calculated. These OLUs can be combined using the overlay functionality of GIS. An overlay of multiple OLUs will give the spatial total overview and show where areas are located where preservation and restoration affect many species and/or processes, hence have high conservation priority, and point to gaps in knowledge.

Identifying the necessary spatial extent and key landscape connections

The vast amount of knowledge on spatial processes in population biology and ecosystems science that has developed during the past decades, particularly in the wake of Levin's (Levin 1992) seminal paper, gave spatial issues a prominent place on the ecological research agenda. Very recently, great progress has been made in spatial analysis in both population biology and ecosystem science. In population biology, research on dispersal, migration and spatial landscape use of individuals, gene flow between populations and migration, invasion and expansion of species has made enormous progress. In ecosystem science, our understanding of the way in which surface water and groundwater flows and the transport of nutrients, pollutants and other solutes determine abiotic site conditions for species has greatly improved, predominantly due to increased modelling ability. Our knowledge of the spatial distribution and flow of organisms as well as abiotic processes in the landscape has the potential to be the basis for detailed science-based regional conservation strategies that include spatial planning.

The OLU is situation- and conservation target-specific. For each landscape and conservation target the combination of OLUs and the best spatial conservation strategy will be different. We use an example to demonstrate the benefit of an OLU-based approach, in which we will combine attention for the spatial issues arising from population biology and those from hydrogeological landscape flows.

Case study: Renaturalisation of brook valleys

A consequence of agricultural intensification is the drastic change in the hydrological functioning of catchments. Measures to drain agricultural land have lead to lower groundwater tables, loss of groundwater discharge in (semi-)natural landscape patches, straightening of lower-order streams, dampening of stream water level fluctuations, loss of floodplain habitat, loss of meandering as a natural stream habitat process and a deterioration of stream water quality. These changes have resulted in losses of biodiversity, as many plant and animal species are dependent on the hydrological functioning of the landscape for their regional survival. These losses of biodiversity are additional to the losses due to habitat destruction and fragmentation per se. Our new conceptual framework which combines biotic and hydrological connectivity would therefore be effective for an analysis of the best options for restoration of ecosystem functioning and plant biodiversity in fragmented stream catchments. Restoration often focuses on restoration of single brook characteristics, but when at the spatial scale of the entire brook restoration takes place, water-retaining capacity is increased and natural brook functioning is preserved. This allows ability of the system to cope with climate change (prevents drought and extreme floods). In this case, the OLU is the coherent set of landscape components with their natural hydrological connections ensuring natural hydrological processes and high habitat diversity (gradients).

Within the next phase of Euro-Limpacs, we intend to further work out these ideas in a case study in the Dinkel subcatchment, which is part of one of the research areas in the project, i.e. the Vecht catchment. In this subcatchment, local water authorities are developing new policies for water resource management and nature development to better cope with the future challenges of climate change in the region. It is our intention to use the OLU concept to analyse the various restoration options in terms of hydrogeological and biological connectivity.

Conclusions and perspectives

Recent improvements in our knowledge of spatial processes in population biology and ecosystems science are available for the planning and implementation of regional conservation strategies. We propose that this knowledge should be used for situation-specific regional conservation strategies that combine knowledge from biotic and abiotic processes, pay attention to the landscape settings and the ecologically relevant spatial scales of target species and ecosystem functions, and long-term ecosystem robustness/resilience. Implementation of such spatially planned conservation strategies will be easier and more effective than preservation and restoration of small isolated areas as well as very large areas. As a tool to optimize planning and implementation of such conservation strategies we propose introduce the OLU-concept. The OLU concept uses spatial information on ecological processes to identify the minimal set of landscape elements, and their configuration, that is required for regional survival of species and successful functioning of ecosystem functions without intervention by man. We stress that it is crucial that regional conservation strategies are spatially coherent based on the spatial scales of the ecological, physical and chemical processes that are relevant to preserving the abiotic conditions and flora and fauna of the ecosystem under consideration, and should consider habitat connectivity for key species as well as abiotic connections between ecosystems in the landscape. OLUs can be combined using the overlay functionality of GIS, to create a total overview of the situation. This overview will point out where areas with high preservation and restoration priority are located and what gaps in scientific information exist.

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