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Modelling the impact of rangeland management strategies on (semi-)natural vegetation in Jordan

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Abstract: The regional land-use change model LandSHIFT.R (**Land S**imulation to **H**armonize and **I**ntegrate **F**reshwater Availability and the **T**errestrial Environment – **R**egional version) allows the simulation of rangeland management strategies differing in the maximum applied stocking rates. The objective of the presented study was to analyse the differences in land-use and land-cover change resulting from the application of different management strategies in order to enhance the simulation results of LandSHIFT.R for subsequent environmental impact studies. Therefore, the results of two simulation runs, one with sustainable and one with intensive rangeland management were analysed. Both simulation runs were carried out for Jordan and differ only in the applied rangeland management strategy. The simulations cover a period of 25 years, ranging from 2000 to 2025. Since this study focuses on changes regarding rangeland, the livestock number is the only driving variable that varies over the simulation period. The development of livestock numbers over the simulation period is based on calculations of the economic equilibrium model IMPACT-WATER on livestock water demand under a business as usual scenario.

The simulation results were analysed concerning the differences in areal extent of rangeland and in the spatial distribution of the relative HANPP (**H**uman **A**ppropriation on **N**et **P**rimary **P**roduction). In addition, the simulation results were evaluated with a set of landscape metrics in order to extract the impact of the rangeland management strategies on landscape pattern. The comparative analysis of the simulation results for the year 2025 revealed differences arising from the application of varying rangeland management strategies. The application of the intensive management strategy resulted in a rangeland extent of 9 621 km². In contrast, the application of the sustainable management strategy resulted in a rangeland extent of 12 927 km². The different intensity levels of resource use are reflected in the mean relative HANPP values for rangeland: in 2025, mean relative HANPP values are 58 % for intensive management und 47 % for sustainable management. The evaluated landscape metrics indicated a higher value of landscape fragmentation under the application of the intensive rangeland management strategy.

The sustainable rangeland management strategy is characterizes by a less intensive use of local resources associated with a higher area demand. In contrast, the application of intensive rangeland management results in a lower area demand at the expense of the local resources. The relative HANPP considers this effect and is therefore more suitable to evaluate the grazing intensity than a measure that includes only the fraction of the potential natural vegetation used directly as forage. To conclude, the enhancement of the LandSHIFT.R output with raster maps of relative HANPP and the evaluation with landscape metrics seems suitable to enhance the value of LandSHIFT.R results for environmental impact assessments or studies on biodiversity response.

Keywords: *LandSHIFT.R, FRAGSTATS, GLOWA Jordan River, Middle East, grazing intensity*

1. INTRODUCTION

For terrestrial ecosystems, land-use change is a major driver of biodiversity change (Sala et al., 2000). The conversion of land strongly influences biodiversity via related habitat loss and habitat fragmentation (e.g. Cushman, 2006; Kruess and Tscharntke, 1994). Besides the conversion of land, changes in the intensity of land use also exhibit a strong influence on biodiversity or species abundance (e.g. Zechmeister and Moser, 2001; Oehl et al., 2003). Therefore it is important to consider the intensity of land use in models developed to generate scenarios of land-use and land-cover change. This is an essential prerequisite for the development of scenarios including environmental policies.

The regional land-use change model LandSHIFT.R (Koch et al., 2008) implements the simulation of grazing with different management strategies. The objective of this study was to quantify and visualize the impact of two different rangeland management strategies and the resulting grazing intensities on (semi-)natural vegetation, in order to make LandSHIFT.R results more valuable for environmental impact assessments or studies on biodiversity response to land-use change. For this reason, LandSHIFT.R was applied to simulate changes in areal extent of rangelands in Jordan and the associated grazing intensity under a business as usual (BAU) scenario. Two simulation runs were carried out, one with sustainable rangeland management and one with intensive rangeland management. The model output of LandSHIFT.R, which comprises maps on the dominant land-use type as well as a set of indicators representing the area loss due to land-use and land-cover change, was extended by maps of the relative human appropriation of net primary production (rel. HANPP). To extract the differences resulting from various grazing intensities, the results were compared with respect to the areal extent of rangeland and the rel. HANPP of rangeland. In addition, a set of landscape metrics was calculated to analyse the impact of different rangeland management strategies on landscape pattern.

2. MATERIALS AND METHODS

2.1. The study region

The presented study was carried out for Jordan. Jordan is bordered by Syria in the north, by Iraq and Saudi Arabia in the east, and by Israel as well as the West Bank in the west (Figure 1). The country area of the Jordan territory adds up to 89 458 km². The climate is characterized by hot, dry summers and cool, wet winters. Mean annual precipitation ranges from about 120 mm in the south and south-east to 660 mm in the north-west. In 2000, the population of Jordan numbered approx. 5 million (FAO, 2009), of which about one fifth lived in Amman, the administrative capital and largest city of the country (United Nations, 2009). With about 2.2 million goats and sheep (FAO, 2009), the production of small ruminants is an important factor of Jordan's agricultural sector.

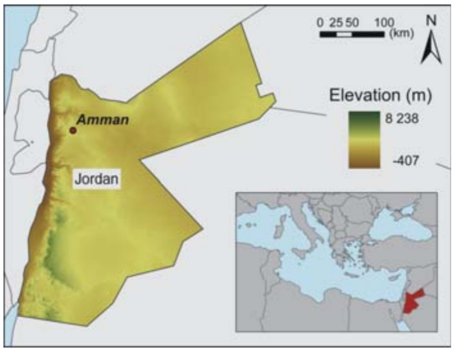

Figure 1. The study was carried out for Jordan.

2.2. LandSHIFT.R – Model overview

The modelling system LandSHIFT (**Land S**imulation to **H**armonize and **I**ntegrate **F**reshwater Availability and the **T**errestrial Environment) is designed to generate spatially explicit, mid- to long-term scenarios of land-use and land-cover change (Alcamo and Schaldach, 2006; Schaldach et al., 2006). Driving variables of LandSHIFT are demands for land intensive commodities (e.g. livestock numbers) and assumptions on policy and socio-economy. The rationale of LandSHIFT is to regionalize the demands for land intensive commodities in a consistent and systematic way.

In this study, a regional application of LandSHIFT, named LandSHIFT.R, was applied (Koch et al., 2008). The LandSHIFT.R version employed in this study comprises three functional components:

- The land-use change module (LUC-module) is the core component of LandSHIFT.R. It operates on two spatial levels. Driving variables are specified on the state level (macro level) and the geographic extent is defined by a regular grid with a spatial resolution of 1 km × 1 km (micro level). Each grid cell features information about the dominant land-use type and the population density. The rationale is to allocate demands for land intensive commodities to the grid cells most suitable for the specific commodity. The LUC-module includes sub-modules to represent human decision making for the three land-use activities "Urban", "Food crops and irrigation" and "Livestock".
- The second component, a productivity module for (semi-)natural vegetation is based on the WADISCAPE model (Köchy et al., 2008). WADISCAPE simulates the growth and dispersal of herbs and dwarf shrubs in artificial wadi landscapes. Vegetation dynamics are controlled by water availability that varies with terrain slope, aspect, and topographic conditions. Information about stocking capacity and non-linear correlation functions between stocking rate of small ruminants (goats and sheep) and productivity of (semi-)natural vegetation are provided to the LUC-module.
- The third component, a productivity module for cropland is based on a modified version (Stehfest et al., 2007) of the ecosystem model DayCent (Parton et al., 1998). Up to now, the information exchange between the LUC-module and the productivity module for cropland is unidirectional. The productivity module provides information on crop yields to the LUC-module. This information is essential to determine the local supply of a specific crop on a grid cell and, as a result, the total amount of cells required to meet the demand. In addition, local crop yields are taken into account when determining the suitability of a grid cell for specific crop categories.

This study focuses on the functionality of the sub-module representing the land-use activity "Livestock". The task of this sub-module is to spatially allocate rangeland. The sub-module is based on non-linear correlation functions between stocking rate and productivity of (semi-)natural vegetation as well as raster maps on stocking capacities, both generated with WADISCAPE. For the base year, LandSHIFT.R allocates the area for "Permanent meadows and pastures" given by FAOSTAT for the year 2000 (FAO, 2009), corrected by the fraction of goats and sheep in the total number of range herbivores. Based on landscape productivity, forage demand, and rangeland management strategy, the local grazing rates are adapted and assigned to the grid cells. In the next time step, this stocking rate is used to assess the local productivity for (semi-)natural vegetation via the cell specific correlation function. Under consideration of the feed demand per livestock unit (LU), the local stocking rate is calculated from the productivity and assigned to the grid cell. This procedure is repeated for each simulation time step. The transient simulation is the prerequisite for this implemented feedback.

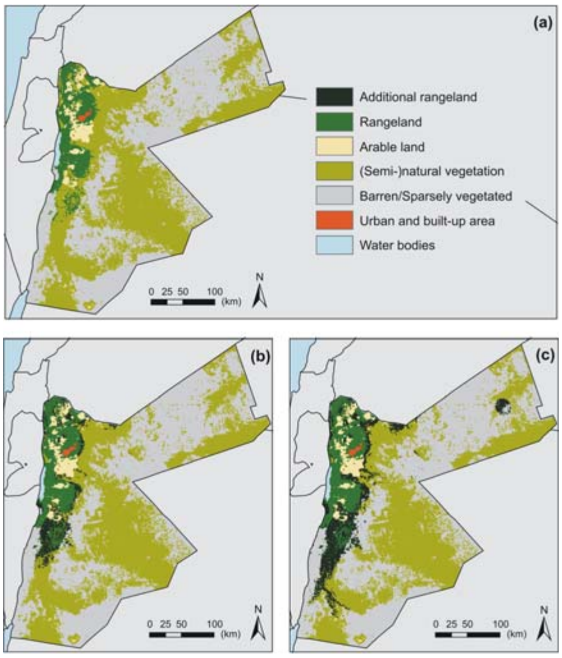

Figure 2. Simulated land-use and land-cover maps (a) for 2000 as well as for 2025 (b) with intensive and (c) sustainable grazing management. The simulated rangeland extent for the year 2000 is equal for both simulation runs. The category "Additional rangeland" describes the change in rangeland up to 2025 compared to 2000.

The sub-module representing the land-use activity "Livestock" comprises the simulation of sustainable and intensive rangeland management. The sustainable management strategy differs from the intensive management strategy in the way it deals with the exceedance of the local sustainable stocking capacity (SSC). The SSC is defined as one third of the maximum stocking capacity, which is the number of sheep and goats per hectare for which the vegetation provides sufficient food in 9 of 10 years in year-round grazing. In case that the calculated local stocking rate exceeds the local SSC, and sustainable rangeland management is applied, the stocking rate is set to the SSC. With the intensive rangeland management strategy, the local stocking rate is not limited by the SSC, i.e., the local stocking rate is exclusively restricted by the productivity of (semi-)natural vegetation.

A comprehensive description of the validation of LandSHIFT.R is given in Koch et al. (in preparation). Validation efforts were made for the Jordan River Region that comprises Israel, Jordan and the Palestinian Authority. The predictive performance of spatially explicit land-use change models refers to both location and quantity of change (Pontius, 2000). Most attempts to validate the location of change base upon a pixel-by-pixel comparison of a simulated map and a reference map of land-use change (e.g. Pontius et al., 2004). These attempts require a second statistically independent land-use data set. Since such a data set is not available, the location of change is validated by testing the plausibility of the model assumptions concerning the suitability for the three land-use activities. This is done by a relative operating characteristic (ROC) analysis (Pontius and Schneider, 2001). The performance measure of the ROC analysis is the area under curve (AUC), calculated by trapezoidal approximation. The ROC analysis was carried out for all three land-use activities. The resulting AUC values are 0.9 for "Urban", 0.74 for "Food crops and irrigation", and 0.84 for "Livestock". All three AUC values are significantly higher than the value for randomly distributed suitability values (0.5) and hence indicate that changes in land use can be found predominantly at locations where LandSHIFT.R allocates high suitability values. Since census data on urban area per state is not available and available data on the extent of rangeland was included in the development of the base year distribution, the validation of quantity was performed for the land-use activity "Food crops and irrigation". A comparison of the simulated extent of cropland with census data for the year 2000 (FAO, 2009) showed an underestimation of cropland area by 4 %.

2.3. Model experiments

Two simulation runs were carried out, one with intensive rangeland management and one with sustainable rangeland management. The simulations operate on a 5-year time step for a period of 25 years, ranging from

2000 to 2025. The spatial resolution of the output maps is 1 km × 1 km. In 2000, the population of Jordan numbered 5 007 330 inhabitants. About 232 338 tonnes of fruits, 923 537 tonnes of vegetables, and 43 838 tonnes of cereals were produced domestically. Altogether, sheep and goat stocks in Jordan added up to 2 172 638 (specifications on population, crop production, and livestock are 3-year averages from 1999-2001 given by FAOSTAT; FAO, 2009).

Since the focus of this study is on grazing, the areal extent of all land-use activities except "Livestock" remains static on the year 2000 level, i.e., the livestock number is the only driving variable that changes over the simulation period. The development of livestock numbers over the simulation period is based on calculations of the economic equilibrium model IMPACT-WATER on livestock water demand under a business as usual scenario (Rosegrant et al., 2002). By 2010 the increase in livestock water demand accounts for 26 % compared to 2000, and by 2025 it accounts for 83 % compared to 2000. The increase is directly transferred to the livestock numbers. Between 2000 and 2010 and accordingly 2010 and 2025, a linear increase is assumed. The conversion of statistical data on goat and sheep stocks to LU is carried out as follows: one sheep or goat accounts for 0.125 LU (Seré and Steinfeld, 1995). In addition, a regional factor of 0.42 is applied that considers the geographical variability in animal body size (Seré and Steinfeld, 1995). The multiplication of the two factors results in a conversion factor of 0.05 LU, i.e., one sheep or goat in Jordan equals 0.05 LU. In correspondence with the range of the WADISCAPE calculations, the stocking rate for both rangeland management strategies in LandSHIFT.R is limited to 1 LU per ha.

The daily feed demand per goat or sheep is 1.35 kg dry matter (Perevolotsky et al., 1998) of which 30 % is supposed to be covered by grazing (Al-Jaloudy, 2001). Following de Leeuw and Tothill (1993), the consumable fraction of forage is set to 30% of the above-ground biomass.

2.4. Quantifying the environmental impact of grazing

In order to quantify and visualize the environmental impact of different grazing intensities, grid cells assigned as rangeland feature, in addition to the dominant land use type, information on the rel. HANPP. The rel. HANPP is derived from the HANPP that indicates "the aggregate impact of land use on biomass" (Haberl et al., 2007a). The HANPP is calculated as given in Haberl et al., (2007b):

$$HANPP = \Delta NPP_{LC} + NPP_h \qquad (1)$$

ΔNPP_{LC} NPP changes induced by soil degradation, soil sealing, and ecosystem change,

NPP_h NPP harvested or destroyed during harvest.

Under consideration of (1), the rel. HANPP is calculated as

$$rel.\,HANPP = \left(\frac{HANPP}{NPP_0}\right) \cdot 100 \;\; [\%] \qquad (2)$$

NPP_0 NPP of the potential natural vegetation.

NPP_0 is derived from the non-linear correlation functions between stocking rate and productivity of green biomass applying a stocking rate of zero. The NPP of the actually prevailing vegetation (NPP_{act}), which is determined via the applied stocking rate in the previous time step, is subtracted from the NPP_0 in order to asses ΔNPP_{LC}. Since the focus of this study is on rangeland, the NPP_h displays the fraction of NPP_{act} that is used directly as forage.

2.5. Analysis with landscape metrics

In order to quantify the impact of different rangeland management strategies on the change of landscape pattern, the results of the two simulation runs were analysed with a set of landscape metrics. A recent overview of the use of landscape metrics and indices is given in Uuemaa et al. (2009).

For the evaluation of the simulation results with landscape metrics at the class level, the land-use and land-cover maps for the years 2000 and 2025 were combined with the corresponding maps of rel. HANPP. Therefore, the land-use and land-cover types were divided into the two classes "heavily human-influenced vegetation cover"

Table 1. Classification of land-use and land-cover types for the analysis with landscape metrics.

Class 1	Class 2
urban/built-up area	shrub land
fruits	grassland
vegetables	permanent wetland
cereals	cropland/natural vegetation mosaic
other crops	barren/sparsely vegetated
rangeland (rel. HANPP <= 50 %)	snow, ice and water
	rangeland (rel. HANPP > 50 %)

(Class 1) and "(semi-)natural vegetation cover" (Class 2) (Table 1). Class 2 was evaluated with a set of metrics at the class level regarding fragmentation and connectivity of patches, whereas a patch is a cluster of connected cells of the same class. A set of straightforward metrics at the class level was chosen. The number of patches (NP) was chosen to describe the subdivision or fragmentation of the class under consideration. The connectance (CONNECT) describes the connectivity of the class under consideration. The calculation of connectance was done with a threshold distance of 10 km. The calculations were carried out with the software package FRAGSTATS. A detailed description of the software package and the applied metrics is given in McGarigal et al. (2002).

3. RESULTS

The simulation of land-use and land-cover change resulted in 368 km² urban/built-up area, an arable land extent of 2 425 km² and 6 464 km² rangeland for the year 2000 (Figure 2). A further expansion of urban/built-up area as well as arable land is not taken into account in this study. Hence, the respective area extents remain constant over the entire simulation period. By 2025 the spatial extent of rangeland under intensive management amounts to 9 621 km². This is an increases of 49 % compared to the rangeland extent simulated for the year 2000. In contrast, the rangeland under sustainable management doubled. This equates to a rangeland extent of 12 927 km² (Figure 3).

The visualization of the rel. HANPP on rangeland reveals clear differences between the two rangeland management strategies (Figure 4). In 2025, the rel. HANPP under intensive rangeland management ranges from 30 % to 88 % and the rel. HANPP under sustainable rangeland management ranges from 8 % to 73 %. Mean rel. HANPP values for the year 2025 are 58 % for intensive management and 47 % for sustainable management. It is important to keep in mind that equal rel. HANPP values do not necessarily result in equal forage production values on the respective grid cell.

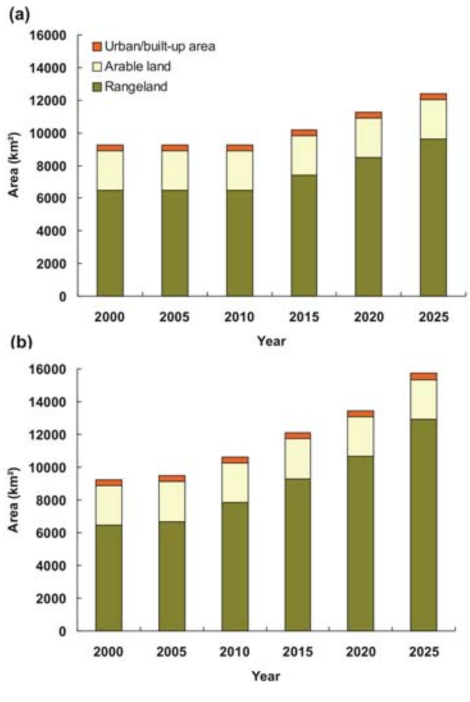

Figure 3. Development of urban/built-up area, arable land and rangeland for the simulation runs with (a) intensive and (b) sustainable rangeland management.

Because none of the simulations for the year 2000 results in rel. HANPP values equal or higher than 50 %, the processed map for the evaluation of landscape metrics is identical for both management strategies. The evaluation of these maps disclosed 18 patches (NP) of the class "(semi-)natural vegetation cover" and a connectance (CONNECT) of 20 %. The analysis of the processed map for the year 2025 under intensive rangeland management showed 135 patches and a connectance of 5.7 %. The analysis of the corresponding map under sustainable management showed 111 patches and a connectance of 6.3 %.

4. DISCUSSION AND CONCLUSIONS

The combination of land-use and land-cover maps with maps displaying the rel. HANPP reveals the main difference between the two rangeland management strategies. The sustainable management strategy is characterized by less intensive use of local resources. However, the area demand required to fulfil the demand for forage is higher as when applying the intensive rangeland management strategy. On the other hand, the pressure on local resources is much higher under the intensive management strategy.

A secondary effect, which is not observable in maps of the dominant land-use or land-cover type, is the reinforcing effect of high stocking rates on the productivity of (semi-)natural vegetation. The application of intensive rangeland management results in a larger reduction of landscape productivity. This effect is implemented in LandSHIFT.R via the correlation functions between stocking rate and landscape productivity, calculated by the WADISCAPE model (Köchy et al., 2008). The rel. HANPP considers this effect in terms of NPP changes induced by applied management practices (ΔNPP_{LC}). For this reason, the rel. HANPP is more suitable to evaluate the grazing intensity than a measure that represents solely the fraction of the NPP_0 used directly as forage as e.g. the stocking rate.

Taking into account the rel. HANPP for the analysis of land-use and land-cover maps with landscape metrics, allows the inclusion of grazing intensities into the analysis of landscape pattern. Under the conditions described above, NP showed a higher increase and CONNECT showed a higher decrease under the intensive management strategy than for the sustainable management strategy. The combination of these two measures indicated a higher value of landscape fragmentation under the application of the intensive rangeland management strategy. A difficulty of the evaluation of landscape fragmentation with landscape metrics is the choice of an adequate threshold value to discriminate between rangeland classified as “heavily human-influenced vegetation cover” or “(semi-)natural vegetation cover”. One improvement strategy could be to derive the threshold value depending on climate conditions (e.g. precipitation), to depict the influence of grazing on landscape productivity.

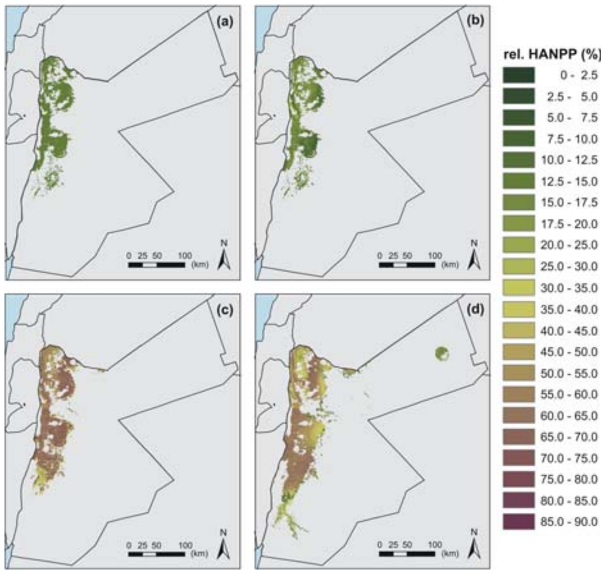

Figure 4. Spatial distribution of relative HANPP in 2000 applying intensive (a) and sustainable (b) rangeland management and in 2025 applying intensive (c) and sustainable (d) rangeland management.

Nevertheless, the enhancement of the LandSHIFT.R output with raster maps of rel. HANPP and the evaluation with landscape metrics seems suitable to enhance LandSHIFT.R results for environmental impact assessments or studies on biodiversity response. Since the application of moderate grazing is discussed as one possibility to maintain the open landscapes in the Mediterranean region (Köchy et al., 2008), the enhanced simulation results of LandSHIFT.R could be used to support decision on future strategies regarding environmental policies or the assignment of conservation areas. Possible other applications are analyses of vertical water transport since grazing intensity strongly influences the leaf area index (Menzel et al., submitted) or studies on nutrients flows with livestock as vector organic materials and mineral nutrients from and to rangeland (Bantiono and Buerkert, 2001).

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REFERENCES

Alcamo, J., and Schaldach, R. (2006), LandShift: global modelling to assess land use change. Proceedings of the 20th International Conference on Informatics for Environmental Protection. Shaker Verlag GmbH, Aachen, pp. 223–230.

Al-Jaloudy, M.A. (2001), FAO Country pasture profile for Jordan, available at http://www.fao.org/ag/AGP/agpc/doc/Counprof/Jordan/Jordan.htm, accessed May 2009.

Bationo, A., and Buerkert, A. (2001), Soil organic carbon management for sustainable land use in Sudano-Sahelian West Africa. *Nutrient Cycling in Agroecosystems*, 61, 131–142.

Cushman, S.A. (2006), Effects of habitat loss and fragmentation on amphibians: A review and prospectus. *Biological Conservation*, 128, 231–240.

FAO (2009), FAOSTAT Database. Food and Agriculture Organization of the United Nations, available at http://www.fao.org, accessed in March, 2009.

Haberl, H., Erb, K.H., Krausmann, F., Gaube, V., Bondeau, A., Plutzar, C., Gingrich, S., Lucht, W., and Fischer-Kowalski, M. (2007a), Quantifying and mapping the human appropriation of net primary production in earth’s terrestrial ecosystems. *Proceedings of the National Academy of Sciences of the United States of America*, 104, 12942–12947.

Haberl, H., Erb, K.H., and Krausmann, F. (2007b), Human appropriation of net primary production (HANPP). Internet Encyclopaedia of Ecological Economics, available at http://www.ecoeco.org/pdf/2007_march_hanpp.pdf .

Koch, J., Schaldach, R., and Köchy, M. (2008), Modeling the impacts of grazing land management on land-use change for the Jordan River region. *Global and Planetary Change*, 64, 177–187.

Köchy, M., Mathaj, M., Jeltsch, F., and Malkinson, D. (2008), Resilience of stocking capacity to changing climate in arid to Mediterranean landscapes. *Regional Environmental Change*, 8, 73–78.

Kruess, A., and Tscharntke, T. (1994), Habitat fragmentation, species loss, and biological control. *Science*, 264, 1581–1584.

de Leeuw, P.N., and Tothill, J.C. (1993), The concept of rangeland carrying capacity in Sub-Saharan Africa — myth or reality. In: Behnke Jr., R.H., Scoones, I., Kerven, C. (Eds.), Range Ecology at Disequilibrium. New Models of Natural Variability and Pastoral Adaptation in African Savannas. IIED, Overseas Development Institute, London, pp. 77–88.

McGarigal, K., Cushman, S.A., Neel, M.C., and Ene, E. (2002), FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at http://www.umass.edu/landeco/research/fragstats/fragstats.html

Menzel, L., Koch, J., Onigkeit, J., and Schaldach, R. (submitted), Modelling the effects of land-use and land-cover change on water availability in the Jordan River region.

Oehl, F., Sieverding, E., Ineichen, K., Mäder, P., Boller, T., and Wiemken, A. (2003), Impact of Land Use Intensity on the Species Diversity of Arbuscular Mycorrhizal Fungi in Agroecosystems of Central Europe. *Applied and Environmental Microbiology*, 69, 2816–2824.

Parton, W.J., Hartman, M., Ojima, D.S., and Schimel, D. (1998), DAYCENT and its land surface submodel: description and testing. *Global and Planetary Change*, 19, 35–48.

Perevolotsky, A., Landau, S., Kababia, D., and Ungar, E.D. (1998), Diet selection in dairy goats grazing woody Mediterranean rangeland. *Applied Animal Behaviour Science*, 57, 117–131.

Pontius, R.G. (2000), Quantification error versus location error in comparison of categorical maps. *Photogrammetric Engineering and Remote Sensing*, 66, 1011-1016.

Pontius, R.G., Huffaker, D., and Denman, K. (2004), Useful techniques of validation for spatially explicit land-change models. *Ecological Modelling*, 179, 445-461.

Pontius, R.G., and Schneider, L.C. (2001), Land-cover change model validation by an ROC method for the Ipswich watershed, Massachusetts, USA. *Agriculture Ecosystems & Environment*, 85, 239-248.

Rosegrant, M.W., Cai, X., and Cline, S.A. (2002), World water and food to 2025: Dealing with scarcity. International Food Policy Research Institute, Washington, DC.

Sala, O.E., Chapin III, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., LeRoy Poff, N., Sykes, M.T., Walker, B.H., Walker, M., and Wall, D.H. (2000), Global biodiversity scenarios for the year 2100. *Science*, 287, 1770–1774.

Schaldach, R., Alcamo, J., and Heistermann, M. (2006), The multiple scale land use change model LandShift: a scenario analysis of land use change and environmental consequences in Africa. 3rd Biennial meeting of the International Environmental Modelling and Software Society, Burlington, Vermont, 9-13 July 2006, CD ROM.

Seré, C., and Steinfeld, H. (1995), World livestock production systems – Current status, issues and trends. FAO Animal Production and Health Paper No. 127. Food and Agriculture Organisation of the United Nations, Rome.

Stehfest, E., Heistermann, M., Priess, J.A., Ojima, D.S., and Alcamo, J. (2007), Simulation of global crop production with the ecosystem model DayCent. *Ecological Modelling*, 209, 203–219.

United Nations, Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat (2009), World population prospects: the 2006 revision and world urbanization prospects: the 2005 revision. Available at http://esa.un.org/unpp, accessed in March, 2009.

Uuemaa, E., Antrop, M., Roosaare, J., Marja, R., and Mander, Ü. (2009), Landscape Metrics and Indices: An Overview of Their Use in Landscape Research. *Living Reviews in Landscape Research*, 3, available at http://www.livingreviews.org/lrlr-2009-1, cited at 30 March 2009.

Zechmeister, H.G., and Moser, D. (2001), The influence of agricultural land-use intensity on bryophyte species richness. *Biodiversity and Conservation*, 10, 1609–1625.