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Modeling the impacts of grazing land management on land-use change for the Jordan River region

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ABSTRACT

In this article, we describe a simulation method for investigating the impacts of different grazing land management strategies on the productivity of (semi-)natural vegetation and the resulting feedback on land-use change. In a first application, we analyze the effects of sustainable and intensive grazing land management in the Jordan River region. For this purpose, we adapt and use the regional version of the spatially explicit modeling framework LandSHIFT. Our simulation experiments indicate that the modeled feedback mechanism has a strong effect on the spatial extent of grazing land. Consequently, the results of our study underline that the inclusion of such feedback mechanisms in land-use models can help to represent and analyze the complex interactions between humans and the environment in a more differentiated and realistic way, but they also identify the demand for more detailed empirical data on grazing land degradation in order to further improve the explanatory power of the model.

1. Introduction

The eastern Mediterranean ecosystems pertain to the class of dryland systems and are therefore potentially prone to desertification. Desertification is defined by the Convention to Combat Desertification as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (UNEP, 1994). The causes of desertification are still under discussion but Geist and Lambin (2004) identify cropland expansion, overgrazing and infrastructure expansion as proximate causes of desertification driven by climatic and economic factors, institutions, national policies, population growth, and remote influences.

Current results from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change project increasing mean annual temperatures and decreasing precipitation amounts accompanied by a very likely increase in length and frequency of dry spells for the Mediterranean region (Christensen et al., 2007). These climate projections and the projected high population growth rates (FAO, 2008) put additional pressure on the ecosystems of the region and presumably aggravate the desertification risk.

One possibility to avoid or at least diminish dryland degradation is to improve agricultural practices towards sustainable management (Millennium Ecosystem Assessment, 2005a). In this context, the management of grazing systems deserves special attention. Consistently high stocking rates are identified as a cause of changes of vegetation cover/composition (Gillson and Hoffman, 2007) and soil degradation (Ibanez et al., 2007). These effects can lead to a reduction of productivity of forage grasses (van de Koppel et al., 2002) that in consequence can endanger the regional livestock production systems and human food security. Moreover, the studies of Alados et al. (2004) and Alhamad (2006) show that intensive grazing has negative impacts on the biodiversity of Mediterranean grassland ecosystems.

In this article, we describe a newly developed simulation based method that uses the dynamic, spatially explicit land-use model LandSHIFT for investigating the impacts of different grazing land management strategies on the productivity of (semi-)natural vegetation and the resulting feedback on land-use and land-cover changes. We present the results of a first application of this method in a case study for the Jordan River region in the Middle East which differentiates between intensive and sustainable grazing management. Furthermore, in a sensitivity study we explore the model dynamics under different assumptions regarding the reversibility of grazing related vegetation changes and their effects on productivity (Cingolani et al., 2005).

2. Model description

2.1. Overview

The modeling framework LandSHIFT (*Land* *S*imulation to *H*armonize and *I*ntegrate *F*reshwater Availability and the *T*errestrial Environment) is designed to develop integrated, spatially explicit, mid- to

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long-term land-use and land-cover scenarios (Alcamo and Schaldach, 2006; Schaldach et al., 2006). The exogenous driving forces of LandSHIFT are demands for area intensive products like agricultural commodities and housing as well as assumptions on policy and socio-economy. The main model output consists of time series on land-use and land-cover maps and a set of indicators (e.g. area statistics or maps on stocking densities).

The modularized structure of the framework facilitates the integration of functional components which represent key elements of the land-use system. The framework's regional application used in this study, called LandSHIFT.R, consists of three functional components: a productivity module for cropland, a productivity module for (semi-)natural vegetation for grazing and a land-use change module, in the following referred to as LUC-module (Fig. 1). The productivity module for cropland is based on a modified version of the ecosystem model DayCent (Parton et al., 1998). The main task of this module is to provide crop yields to the LUC-module. The productivity module for (semi-)natural vegetation is based on the WADISCAPE model (Köchy, 2007; Köchy et al., 2008), which delivers information on current and future stocking capacity and landscape productivity to the LUC-module. The simulation of future stocking capacity and production of green biomass is performed under the assumption of changing climate conditions and allows for the indirect inclusion of the effects of climate change on the spatial distribution of land use. Within the LUC-module, the demand for area intensive products is regionalized to a raster map.

2.2. The DayCent model

Information on the local crop yield of a raster cell is essential to determine the local supply and as a result, the total amount of cells that are required to fulfill the demand for a specific agricultural commodity. Additionally, local productivity serves as a factor within the suitability assessment (see 2.4). We use data on wheat yields under rain-fed and irrigated conditions for the climate normal (1961–1990), calculated with a raster version of the ecosystem model DayCent (Stehfest et al., 2007). The DayCent model (Parton et al., 1998) incorporates a detailed representation of plant growth, soil water fluxes and nutrient dynamics. The yield data is available in grid format with a spatial resolution of 30 arc min and is geographically mapped to the 30 arc sec cells.

2.3. The WADISCAPE model

Landscape productivity was simulated with WADISCAPE 3.2.3 (Köchy, 2007; Köchy et al., 2008). WADISCAPE simulates the growth and dispersal of herbs and dwarf shrubs in artificial (fractal) wadi landscapes (wadiscapes) of 1.5 km × 1.5 km. Vegetation dynamics are controlled by water availability, which varies with slope angle, aspect, and topographic position. The simulated dynamics are based on validated fine-grained models of annuals (Köchy, 2006; Köchy et al., 2008) and dwarf-shrubs (Malkinson and Jeltsch, 2007) and have been scaled up to WADISCAPE's cell size of 5 m × 5 m (Jeltsch et al., 2008). Grazing of the vegetation by small livestock (goats and sheep) is realized by randomly selecting cells and removing biomass (on average 1.35 kg dry matter/animal per day). Cells are selected and grazed until the food demand for the specified stocking density is met. The simulations were run for five slope classes (0°, 10°, 15°, 20°, 30°) with six different artificial landscapes in each class to account for the variability of topography. Variation among climatic regions was considered by repeating the simulations for five classes of mean annual precipitation (100, 300, 450, 600, and 800 mm).

The annual time series of precipitation, driving the simulations, were sampled from the output of the regional climate model MM5 ((Grell et al., 1995), provided by H. Kunstmann, IMK-IFU, pers. comm). The regional climate model was used with a resolution of 54 km and was driven by the global circulation model ECHAM4 using the A2 scenario.

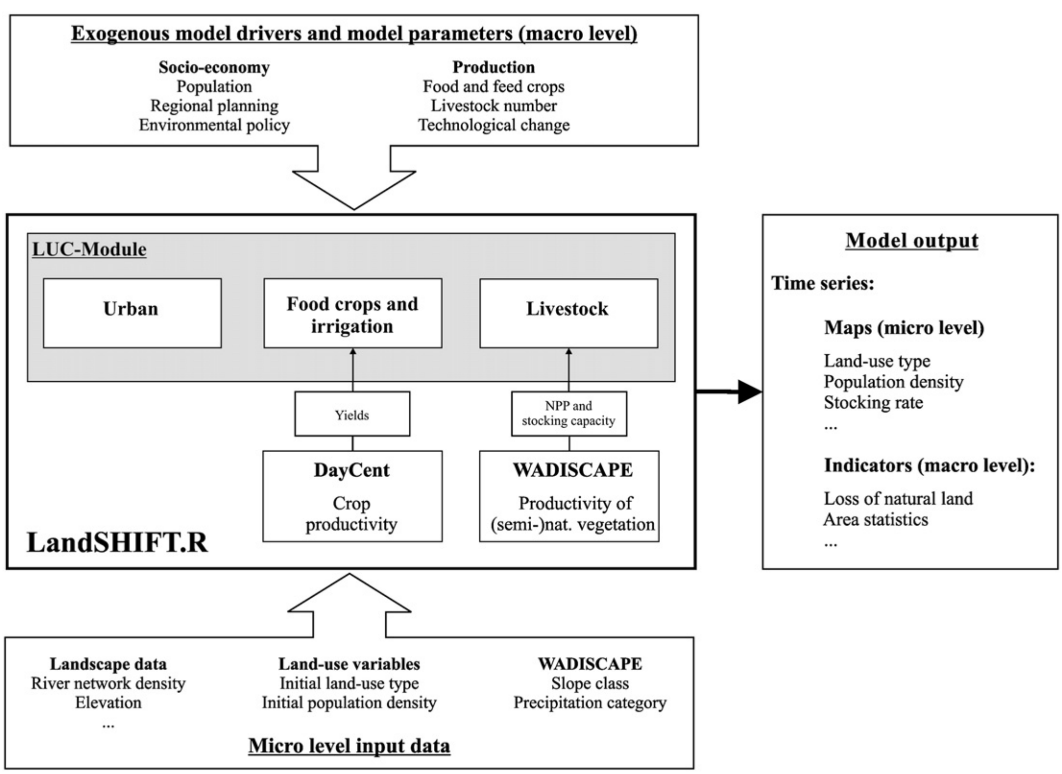

Fig. 1. Schematic representation of LandSHIFT.R. The current model version consists of three modules: a productivity model for cropland, a productivity module for landscape productivity and the LUC-module. The LUC-module is the core element of LandSHIFT.R.

The simulated annual biomass production per cell was averaged across the artificial landscape. The sigmoid relation between mean productivity and mean annual precipitation across climatic regions is described by a non-linear regression for each landscape slope class and each time slice. The resulting regression equations were then applied to a raster map of mean annual precipitation (900 m grain) conditional on the median slope (derived from a 90 m DEM) of the same cell. In order to determine the stocking capacity of the vegetation, simulations were repeated for stocking rates ranging from 0 to 1.0 LSU/ha for each combination of artificial landscape, slope class, and climatic region to determine the stocking capacity of the landscape. Stocking capacity of a habitat was defined as the number of sheep and goats per hectare for which the vegetation provides sufficient food in 9 of 10 years in year-round grazing. Non-linear regression equations relating stocking capacity to mean annual precipitation were calculated in the same way as for productivity and also applied to the raster map of mean annual precipitation.

The model output shows that without grazing, productivity increases in a sigmoid way with mean annual precipitation (see above). Foraging by sheep and goats reduces the average productivity. This effect is more pronounced, the dryer the landscape. At a point just under the stocking capacity, productivity steeply declines as the grazed herbs produced fewer seeds than required to maintain the ungrazed plant density. This dynamic behaviour forms the basis of the “Livestock” land-use activity of the LandSHIFT.R model (see 2.5).

2.4. The LUC-module

The LUC-module is the core element of LandSHIFT.R and operates on a spatial multi-level hierarchy. The exogenous driving forces are specified on the state level (macro level) and the LUC-module allocates the resulting land requirements for agricultural products and housing to the micro level. The micro level is specified by a grid with a cell size of 30 arc sec (approximately 1 km×1 km). Each grid cell has one dominant land-use type and information on population density. The basic principle is to allocate the land requirements to the grid cells with the highest suitability value for the specific commodity. The land-use type of as many cells as required to meet the demand for this commodity is changed. The modeled land-use types are listed in Table 1, possible land use transitions are listed in Table 2. Land-use changes are calculated in 5-year time-steps.

The LUC-module of LandSHIFT.R includes processes to model the land-use activities “Urban”, “Food crops and irrigation” and “Livestock”. These three activities compete for land resources. We address this competition by a ranking of the activities according to their economic importance, which defines the sequence of execution. Within each land-use activity, the three process steps “pre-processing”, “suitability assessment” and “resource allocation” are carried out. Within the pre-processing step, the input specified on the macro level is converted into a format useable for the two other process steps. The second process step, the suitability assessment, is carried out on the micro level. To assess the suitability of a single grid cell for a certain land-use type, we adapted a method from the field of Multi-Criteria Analysis (Eastman et al., 1995):

$$\text{suit} = \sum_{i=1}^{n} w_i p_i \times \prod_{j=1}^{m} c_j \quad (1)$$

suit	Suitability value of a specific grid cell [0,1]
w_i	Weight of suitability factor *i*
p_i	Suitability factor *i*
c_j	Land use constraint *j*

Each land-use type has a set of related suitability factors and constraints (Table 3). For the “Livestock” activity, the factors and constraints are in parts derived from Wint et al. (2003). Factors, weights and constraints are implemented as time dependent variables on the macro level. The third process step, referred to as resource allocation, is carried out on the micro level. Within this process, the macro level demands are distributed to the micro level grid cells. Calculations for the “Urban” land-use activity follow a rule-based algorithm (Schaldach and Alcamo, 2006). For the “Food crops and irrigation” activity, we use a modified version of the Multi Objective Land Allocation Algorithm, abbreviated MOLA (Eastman, 1995). Within this algorithm, the grid cells are ranked according to their suitability for each crop-type (i.e. objective) and the allocation of areas is carried out following this

Table 1
Land-use and land-cover types implemented in LandSHIFT.R and the mapping scheme for relating these to the IGBP Land Cover Legend. Only the categories of the IGBP Land Cover Legend that occur within the study region are considered

LandSHIFT.R category	IGBP Land Cover Legend
Forest	Evergreen needleleaf forest
	Deciduous broadleaf forest
	Mixed forest
Shrublands	Open shrublands
Woody savannas	Woody savannas
Grasslands	Grasslands
Wetlands	Permanent wetlands
Cereals	Croplands
Fruits	
Vegetables	
Other crops	
Urban	Urban and built-up
Cropland/natural vegetation mosaic	Cropland/natural vegetation mosaic
Barren	Barren or sparsely vegetated
Grazing land	–
Set aside (Fallow)	–

Table 2
Possible land use transitions considered in the LUC-module of LandSHIFT.R

From	To
Natural and semi-natural vegetation	Urban
	Cropland (cereals, fruits, vegetables)
	Grazing land
Grazing land	Urban
	Cropland (cereals, fruits, vegetables)
Cropland (cereals, fruits, vegetables)	Urban
	Set-aside (fallow)
Set-aside (fallow)	Urban
	Cropland (cereals, fruits, vegetables)
	Grazing land

Table 3
Factors and constraints used for the suitability assessment. The last column shows the weights for the suitability factors as used within the case study for the Middle East

Land-use activity	Classification	Description	Weight
Settlement	Suitability factors	Slope	0.5
		Infrastructure	0.5
	Suitability constraints	Land-use transition	
		Conservation area	
Food crops and irrigation	Suitability factors	Productivity	0.34
		Slope	0.33
		Neighborhood to agriculture	0.33
	Suitability constraints	Land-use transition	
		Conservation area	
		Marginal yield	
Livestock	Suitability factors	Productivity	0.2
		Slope	0.2
		Neighborhood to agriculture	0.2
		Proximity to settlements	0.2
		River network density	0.2
	Suitability constraints	Land-use transition	
		Conservation area	
		Marginal yield	

Table 4
Land area (ESRI, 1996) and shares of important land-use categories for Israel, Jordan and Palestine for the year 2000 (FAO, 2008)

	Israel	Jordan	Palestine
Land area [km^2]	20774	89275	6190
Share in land area [%]			
Arable land	15.62	2.15	17.61
Permanent cropland	3.97	1.00	19.93
Permanent meadows and pastures	6.56	8.96	24.92

suitability ranking. Emerging conflicts are resolved by a pair wise comparison: cells claimed by more than one crop type are allocated to the crop type with the higher suitability value. Our modifications of the MOLA algorithm include the allocation of crop demands (given as metric tons) instead of areas and the additional consideration of pattern stability within the conflict resolution step.

2.5. The “Livestock” land-use activity

The task of the “Livestock” land-use activity is to allocate grazing land for forage production. We have improved the resource allocation step of this model process to account for feedback mechanisms between grazing and productivity of (semi-)natural vegetation. The new version is based on non-linear correlation functions between stocking rate and productivity of (semi-)natural vegetation (i.e. landscape productivity), and raster maps on stocking capacities, both generated by the WADISCAPE model (see 2.3). Additionally, the new version provides the opportunity to choose between two allocation modes, representing (a) sustainable and (b) intensive management of grazing land.

The base year allocation of grazing land and the principal approach to dynamically assess the landscape productivity on the micro level are identical for both allocation modes: depending on precipitation category and slope class of a specific grid cell, the associated correlation function is chosen and the local productivity without stocking is assessed. The local stocking rate in livestock units is then calculated from this productivity via the feed demand per livestock unit, and subsequently assigned to the grid cell. In the next time step, this stocking rate is used to derive the new productivity value from the cell specific correlation function. This productivity again serves as calculation basis for the new local stocking rate, as described for the first simulation step. This procedure is repeated for each simulation time step. An important effect of the relationship between stocking rate and productivity is the resulting self-regulation: The allocation of high stocking rates in one time step results in lower landscape productivities in the next time step leading to lower stocking rates. In addition to the dynamic calculation of local landscape productivity, a cell specific value on productivity change due to climate change is taken into account.

The two allocation modes differ for the case that the calculated stocking rate exceeds the local stocking capacity, referred to as overgrazing. Within the allocation mode representing sustainable grazing, the local stocking capacity defines the maximum stocking rate of a grid cell. Each time the stocking rate, assessed via the productivity, exceeds the stocking capacity the stocking rate is set to the stocking capacity. Within the allocation mode representing intensive grazing, this limitation is not applied and the stocking rate is limited by the landscape productivity, only. For our model experiments, we additionally include a grid cell specific parameter RF (=reduction factor) into the model which allows accounting for an irreversible reduction of landscape productivity. The idea is that in each 5-year simulation time step the allocated stocking rate exceeds the grid cells' stocking capacity, local productivity is irreversibly reduced by a defined rate. This reduction becomes operative in the following simulation time step and determines the calculation of the new stocking rate. In case that the landscape productivity falls under a marginal value, the cell becomes unsuitable for grazing in the following time steps.

The maximum stocking rate for both allocation modes is limited to 1.0 livestock units (LSU)/ha, which corresponds to the range of the WADISCAPE calculations (see 2.3).

3. Study region

Our simulations cover the land territories of Israel, Jordan and Palestine. Altogether, the land area adds up to 116 239 km^2, of which 20 774 km^2 pertain to Israel, 89 275 km^2 to Jordan and 6 190 km^2 to Palestine, which is subdivided into the Gaza Strip with 374 km^2 and the West Bank with 5 816 km^2 (ESRI, 1996). The shares of arable land, permanent cropland, and permanent meadows and pastures in the land areas for the year 2000 are listed in Table 4. The study region reaches from 33.38°N, 34.22°E to 29.19°N, 39.30°E (ESRI, 1996) and is located in the Middle East with Israel and the Gaza Strip bordering the eastern part of the Mediterranean Sea.

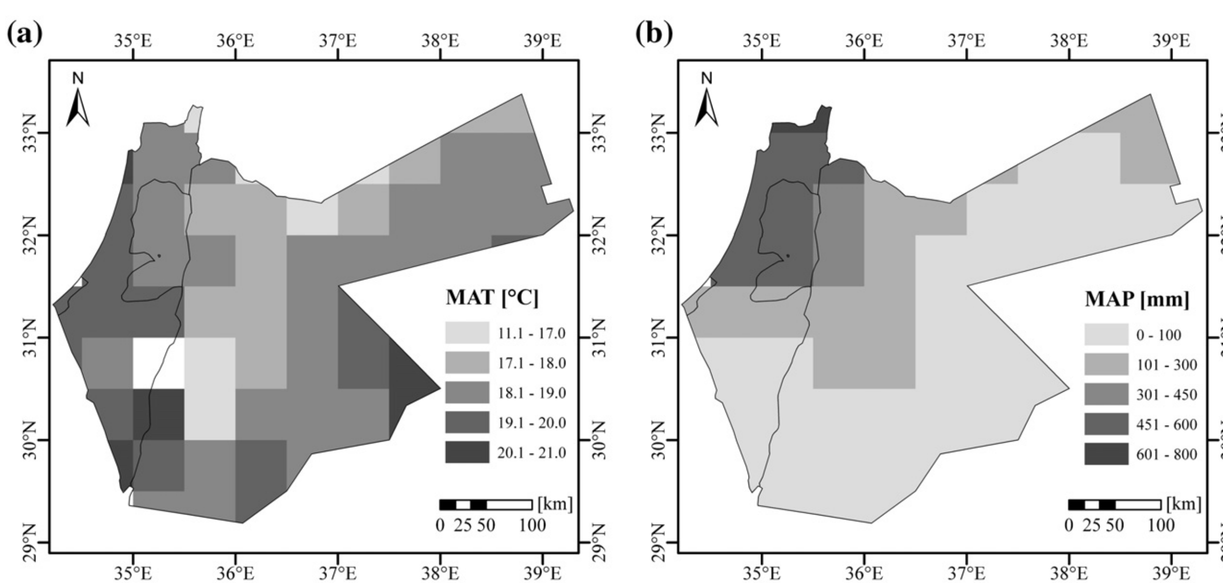

Fig. 2. Spatial distribution of (a) mean annual temperature (MAT) and (b) mean annual precipitation (MAP) for the climate normal 1961–1990 (Mitchell and Jones, 2005).

Table 5
Summary of the data requirements for the case study

Spatial level	Variable	Temporal coverage	Purpose	Comment	Source
State	Crop class production	1999–2001	Baseline definition	Production for the crop classes cereals, fruits (exc. melons) and vegetables (inc. melons)	FAO, 2008
	Total area under crop class	2000		Area harvested for the crop classes cereals, fruits (exc. melons) and vegetables (inc. melons)	
	Total irrigated area under crop class			Area harvested scaled with state specific fractions of irrigated area	Prepared for the case study
	Change in Population	2025, 2050	Exogenous drivers	Change in human population count per state relative to baseline	MEA, 2005b
	Change in crop class production			Crop production change per state relative to baseline; based on IMPACT model results (Rosegrant et al., 2002):	Ringler (pers. comm.)
	Change in crop class yields			it is assumed that demand and supply are in equilibrium at every time step	
	Change in livestock numbers			Assessed from meat production and production changes; based on IMPACT model results (Rosegrant et al., 2002)	
Grid, 30 arc min	Wheat yields	1990–2000	Landscape variable	Yield distribution of wheat influenced by climate, soil and management (fertilization and irrigation)	Stehfest et al., 2007
Grid, 30 arc sec	Land-use and land-cover types	2000	Initial condition	Map of urban area, 4 crop classes, grazing land plus a selection of natural land cover types, based on GLCC IGBP Land cover classification data set (Loveland et al., 2000)	Prepared for the case study
	Population density	2000		Gridded population density	CIESIN, 2004
	Slope		Landscape variable	Slope derived from the HYDRO1k dataset	U.S. Geological Survey, 1998
	River network density			Line density of rivers per grid cell, based on HYDRO1k data set on streams (U.S. Geological Survey, 1998)	Prepared for the case study
	Infrastructure			Line density of roads per grid cell, base on VAMP0 data set on roads (NIMA, 1997)	Prepared for the case study
	Productivity of green biomass	2000, 2050		Productivity without grazing, model output of WADISCAPE	Köchy, 2007; Köchy et al., 2008
	Stocking capacity	2000, 2050		Model output of WADISCAPE	Köchy, 2007; Köchy et al., 2008
	Conservation areas		Zoning regulation	Areas designated as national or international conservation areas	WDPA Consortium, 2004

The terrain is structured with the Great Rift Valley separating East and West Banks of the Jordan River. Israel is subdivided into the low coastal plain, the central mountainous region and the southern Negev desert (CIA, 2008). The Gaza Strip is located in the low coastal plain whereas the terrain of the West Bank is rugged dissected upland. A desert plateau forms the eastern part of Jordan; in contrast the western part can be described as highland area. The lowest point of the study region is the Dead Sea with −408 m a.s.l., the highest point is Jabal Ram in Jordan with 1734 m a.s.l.

According to the Köppen–Geiger climate classification (Peel et al., 2007), the climate in the region can be roughly described as follows: from northwest to southeast there is a climate gradient from a temperate climate with hot and dry summers (northern part of Israel and the West Bank) to arid hot desert (north-eastern part of Jordan and southern parts of Jordan and Israel). The climate in the Gaza Strip, the western middle part of Israel and a part of the north of Jordan is classified as arid hot steppe. The eastern middle part of Israel and the western middle part of Jordan have an arid cold steppe climate, and the eastern middle part of Jordan has an arid cold desert climate. The spatial distribution of mean annual temperature and precipitation for the climate normal 1961–1990 (Mitchell and Jones, 2005) is displayed in Fig. 2. Besides limited natural freshwater resources, current environmental issues in the region are amongst others desertification and overgrazing (Abahussain et al., 2002; Ministry of Environment of The Hashemite Kingdom of Jordan, 2007).

4. Materials and methods

4.1. Data sets and processing

The starting configuration of land-use and land-cover types is based on the IGBP Land Cover Classification dataset from the Global Land Cover Characterization data base (Loveland et al., 2000), derived from AVHRR source imagery dates from April 1992 through March 1993. The mapping of land-use and land-cover types of LandSHIFT.R on the IGBP Land Cover Classification is listed in Table 1.

The LandSHIFT.R routines for suitability assessment and land allocation use grid-level information on landscape characteristics, zoning regulation and land-use related model variables. We apply the GIS software ArcGIS to extract the information from existing global

Table 6
Processed macro level input to LandSHIFT.R for the Millennium Ecosystem Assessment scenario “Order from Strength”

State	Year	Population	Livestock [LSU]	Production change compared to 2000 (%)			Yield change compared to 2000 (%)		
				Cereals	Fruits	Vegetables	Cereals	Fruits	Vegetables
Israel	2000	6 082 667	45 220	0	0	0	0	0	0
Israel	2025	9 166 167	62 485	31	39	51	26	13	7
Israel	2050	10 704 371	73 236	51	79	111	34	21	12
Jordan	2000	4 805 333	114 064	0	0	0	0	0	0
Jordan	2025	8 399 265	253 908	54	77	48	34	34	26
Jordan	2050	10 583 197	329 322	101	166	108	52	58	50
Palestine	2000	3 150 333	45 566	0	0	0	0	0	0
Palestine	2025	5 506 483	107 134	54	77	48	34	34	26
Palestine	2050	6 938 249	138 954	101	166	108	52	58	50

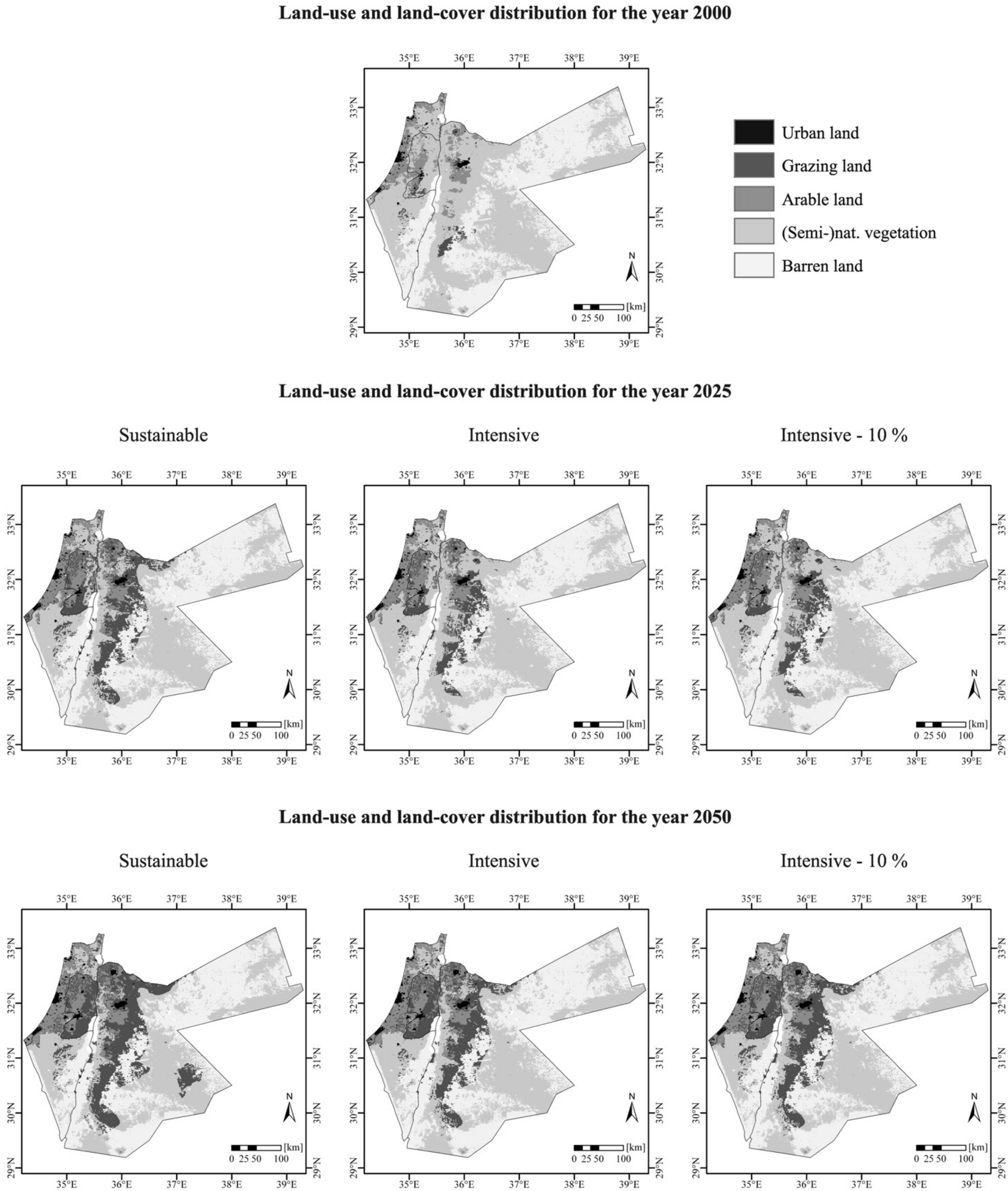

Fig. 3. Land-use and land-cover maps for the simulation runs assuming sustainable grazing land management, intensive grazing land management without productivity reduction and intensive grazing land management with a productivity reduction of 10%.

datasets and geographically map them to the micro level grid cells. Population density is derived from the Global Rural Urban Mapping Project — GRUMP alpha (CIESIN, 2004), while slope data is based on the HYDRO1k data set (U.S. Geological Survey, 1998). The river network density is calculated via the line density of rivers per grid cell, based on the HYDRO1k data set on streams (U.S. Geological Survey, 1998). The information on infrastructure is assessed via the VMap0 data set on roads (NIMA, 1997). In order to derive information of zoning regulation, we map the micro level grid cells to data sets on areas designated as national or international conservation areas (WDPA Consortium, 2004). Moreover, the data set on potential rain-fed and irrigated wheat yields generated with the DayCent model, which is available at a resolution of 30 arc min (Stehfest et al., 2007), is geographically mapped to the micro level grid cells.

The new "Livestock" land-use activity works on a set of 25 non-linear correlation functions, describing the relationship between stocking rate and productivity of (semi-)natural vegetation. The functions are calculated for five precipitation categories (100, 300, 450, 600, and 800 mm) and five slope classes (0°, 10°, 15°, 20°, 30°) by the WADISCAPE model (see 2.3). The functions are separated into sections and fitted by linear regression. Each grid cell of the study region is geographically mapped to a precipitation category and slope class to relate it to the specific correlation function. The spatial distribution of the precipitation category is static over the entire simulation period. The information on productivity change of (semi-)natural vegetation and on the changing stocking capacity, both due to a changing climate is calculated from the raster maps for the years 2000 and 2050 on productivity without grazing and on stocking capacity under assumption of linear transition for each grid cell and each time step.

In the base year allocation step, we regionalize the three year average production value (1999–2001) for the crop classes cereals, fruits (excluding melons) and vegetables (including melons) given by the FAO statistical database (FAO, 2008). The part of the area that is classified as cropland in the IGBP Land Cover data set, where none of the three crop classes is allocated in the base year, is assumed to be used for the production of crops that are not considered within the current LandSHIFT.R version. This area is assigned to the land-use type "other crops" and kept static for the following time steps. In Table 5, the data requirements for the case study are summarized.

4.2. Set-up of the case study: modeling land-use changes in the Middle East

In order to demonstrate the impacts of the improved grazing land allocation method on land-use and land-cover change, we conduct a simulation experiment for the three states Israel, Jordan and Palestine (Jordan River region). For identifying the differences between the grazing land allocation modes "sustainable" and "intensive" as described in Section 2.5, we carry out five simulation runs: (a) one simulation run under the assumption of sustainable grazing management and (b) four simulation runs under intensive grazing management. The simulation runs for intensive grazing use different assumptions on the effects of overgrazing on landscape productivity. The first run represents a very resilient grazing system where overgrazing does not cause irreversible reduction of landscape productivity. In contrast, the other simulation runs assume that overgrazing leads to a decrease of productivity due to changes of vegetation cover/composition and soil degradation which is not reversible within the simulation period of 50 years (van de Koppel and Rietkerk, 2000; Ibanez et al., 2007; Köchy et al., 2008). This behavior is modeled by specifying the parameter RF separately for each model run. In absence of empirical data on grazing land degradation rates for our study region, we perform simulation runs with 10%, 20% and 30% reduction of landscape productivity within each 5-year time step and use them to analyze the sensitivity of our model to this type of degradation. While the 10% reduction rate (equaling 2% per year) is based on the degradation factors discussed by Stéphenne and Lambin (2001) for grazing systems in Burkina Faso, the other rates are hypothetical values in order to illustrate the resulting model dynamics under extreme assumptions.

The simulation experiment exclusively accounts for goats and sheep, assuming a feed demand of 1.35 kg dry matter/animal per day (Perevolotsky et al., 1998) and a fraction of 40% for grazing at the feed composition (Nordblom et al., 1997). We simulate land-use scenarios for a time period of 50 years from the base year 2000 up to the year 2050 in 5-year time steps. Simulations for the base year are also used to initialize the model.

4.3. Scenario description

In this case study, we use data from the Millennium Ecosystem Assessment (MEA) "Order from Strength" scenario. This scenario depicts a "regionalized and fragmented world concerned with security and protection" (Millennium Ecosystem Assessment, 2005b). The "Order from Strength" scenario shows the highest population growth rates and the lowest economic growth rates of all MEA scenarios. We use this scenario to be consistent with the WADISCAPE model results, which are produced for the SRES A2 scenario.

The information on livestock numbers, production change and changing yields due to technological progress is derived from the model output of the global food projection model IMPACT (Rosegrant et al., 2002). Since the MEA scenario presupposes 1997 as base year, the IMPACT data has to be further processed for this study. First, we use FAOStat values for human population, sheep/goat stocks and production (FAO, 2008) to calculate 3-year average values (1999–2001). Second, we identify the trend for these parameters as calculated by IMPACT compared to the year 2000. Thereafter we apply the trends to the average values to get the parameters' development. Since Palestine is not explicitly considered within the IMPACT model, we apply the same trends as for Jordan, implying that Palestine also belongs to the "Other West Asia and North Africa" region.

In order to derive a spatial yield distribution for the three crop classes in the base year, we scale the spatial information on wheat yields

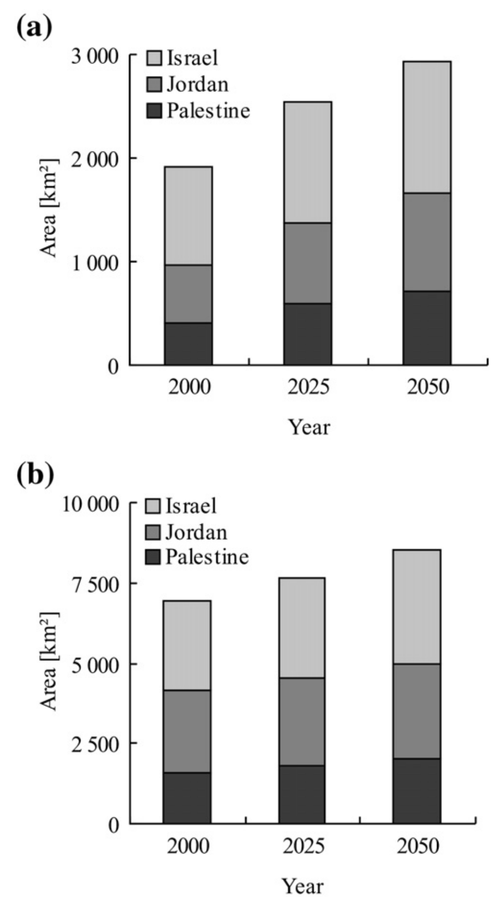

Fig. 4. Development of the absolute area of (a) urban land and (b) arable land for Israel, Jordan and Palestine.

Table 7
Allocated grazing land per state for the five different simulations runs

State	Year	Sustainable	Intensive	Intensive 10%	Intensive 20%	Intensive 30%
		[km^2]	[km^2]	[km^2]	[km^2]	[km^2]
Israel	2000	398	398	398	398	398
Israel	2025	1329	940	1061	1207	1365
Israel	2050	1666	1125	1541	1529	1675
Jordan	2000	1104	1104	1104	1104	1104
Jordan	2025	9510	6204	6316	6552	6917
Jordan	2050	14 403	10 116	10 643	12 524	15 387
Palestine	2000	363	363	363	363	363
Palestine	2025	2662	1915	1901	1973	2098
Palestine	2050	3210	3196	3194	2831	2051

generated with the DayCent model (Stehfest et al., 2007) with the IMPACT yields for wheat, all cereals, (sub-)tropical and temperate fruits, and vegetables (processed for the year 2000). Yield changes are based on IMPACT results, an additional climate effect is not taken into account. We assume one sheep/goat as 0.125 LSU to convert goat and sheep stocks into livestock units. Additionally, we take into account a regional factor of 0.8 for Israel and 0.42 for Jordan and Palestine, which accounts for the livestock weight (Seré and Steinfeld, 1996). This results in a conversion factor of 0.1 LSU for one sheep or goat in Israel and 0.05 LSU for one sheep or goat in Jordan and Palestine. To maintain consistency with the WADISCAPE model results, we double the stocking density value when assessing the productivity for Jordan and Palestine from the correlation functions. Table 6 provides a compilation of the processed main driving forces of LandSHIFT.R.

4.4. Validation

Validation should be an important part of the development process of simulation models. Additionally, validation is essential to achieve credibility in the user community (Rykiel, 1996). In case of spatially explicit simulation models of land-use and land-cover change, the evaluation of predictive performance refers to both location and quantity of change (Pontius, 2002). A typical procedure to evaluate the predictive performance regarding location is to compare a simulated map to a reference map (e.g. Pontius et al., 2004). In addition to the data set used to calibrate the model, this approach requires a second statistically independent data set. For this study, as for many others, there is a lack of data to meet this demand. To validate the quantity of change, we use FAO statistical data on permanent meadows and pastures for the years 2000 and 2005 (FAO, 2008).

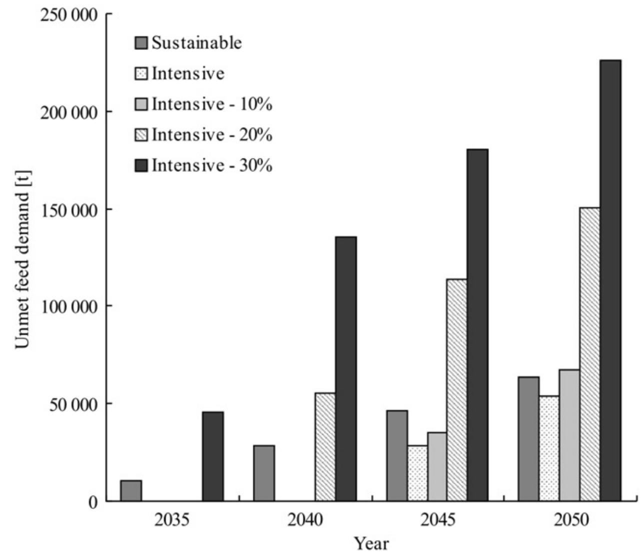

Fig. 6. Development of the unmet feed demand for Palestine. Before 2035, the feed demand in Palestine is met for all five simulation experiments.

5. Results

5.1. Land-use change under sustainable and intensive grazing land management

Fig. 3 shows the land-use maps for the simulation runs with sustainable grazing land management, intensive grazing land management without productivity reduction and with a productivity reduction of 10% for the years 2000, 2025 and 2050. For visualization purposes, we aggregate the land-use types cereals, fruits, vegetables and other crops to the category arable land and the land-cover types forest, natural vegetation mosaic/cropland, shrub land, grassland, woody savannah and wetland to the category (semi-)natural vegetation. The grazing land allocation algorithm applied for the base year 2000 is identical for both grazing land allocation modes resulting in a consistent base year

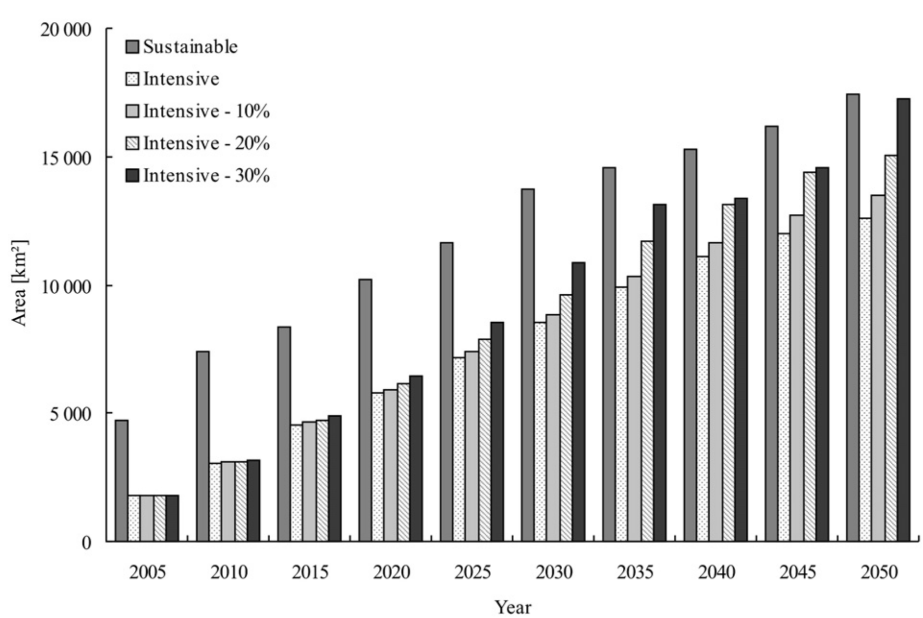

Fig. 5. Comparison of additional grazing land demand compared to the year 2000 for all five simulation runs.

distribution of land-use and land-cover types for all five simulation runs. The base year distribution shows an extent of urban area of 962 km^2 in Israel, 550 km^2 in Jordan and 409 km^2 in Palestine. The extent of arable land in 2000 is assessed as 2778 km^2 in Israel, 2539 km^2 in Jordan and 1602 km^2 in Palestine, the extent of grazing land for the base year is 398 km^2 in Israel, 1104 km^2 in Jordan and 363 km^2 in Palestine. The residual land area is covered with (semi-)natural vegetation or barren land.

Since the “Livestock” land-use activity is in its economic importance subordinate to the land-use activities “Urban” and “Food crops and irrigation”, the land-use changes regarding urban area and arable land are equal for all five simulation runs. The extent of urban area for all three states increases from approximately 1920 km^2 in 2000 by 32% up to 2025 and 53% up to 2050 (Fig. 4a), the extent of arable land for the study region increases from approximately 6920 km^2 in the base year by 11% up to 2025 and 23% up to 2050 (Fig. 4b).

Table 7 summarizes the extent of allocated grazing land for the three considered states and the years 2000, 2025 and 2050. Fig. 5 combines the additional area demand for grazing land compared to the year 2000 for the five simulation runs that were carried out. All simulation runs indicate an unmet feed demand for Palestine, associated with an almost complete utilization of (semi-)natural vegetation for grazing purposes. Fig. 6 demonstrates the development of the unmet feed demand for Palestine.

5.2. Validation of quantity of land-use change

Fig. 7 shows a comparison of the FAO statistical data on permanent meadows and pastures with the simulated areas allocated to grazing land for the base year 2000 and the year 2005.

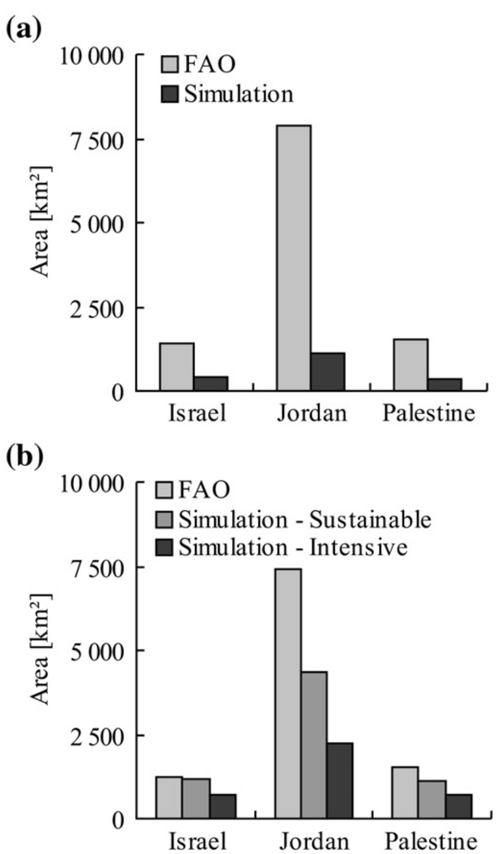

Fig. 7. Comparison of simulated grazing land area (a) for the year 2000 and (b) for the year 2005 with FAO values for permanent meadows and pastures.

6. Discussion

The results of our simulation experiments indicate that the modeled feedback mechanism between grazing management and landscape productivity has a strong effect on land-use change in terms of the spatial extent of grazing land. Assuming that overgrazing does not cause an irreversible reduction of landscape productivity, we see that the area which is allocated to grazing land under the sustainable management strategy exceeds the one allocated under intensive grazing management by far. However, this is achieved by the use of higher stocking rates which may have negative impacts on biodiversity (Alados et al., 2004; Alhamad, 2006) that are not accounted for in our study. The picture is changing when we assume that overgrazing leads to a degradation of the grazing system in form of an irreversible reduction of landscape productivity. For the three simulation runs of the sensitivity study, the differences between sustainable and intensive grazing land management are depicted in Fig. 5: at the beginning, the area demand under the sustainable allocation mode is much higher than under intensive grazing land management but in the long perspective, the area demand under the assumption of intensive management including irreversible productivity reduction approaches the area demand for sustainable grazing. This effect becomes even more apparent in Fig. 6, illustrating the unmet feed demand for Palestine. This demand specifies the amount of forage, which is required but cannot be provided by grazing land, because no (suitable) land area is left to allocate this demand. Consequently, this unmet demand has to be covered by additional feedstock. In 2050, all three simulations delineate a higher unmet demand than the simulation run assuming sustainable grazing land management. These results show that the model is sensitive to irreversible changes of landscape productivity. Nevertheless, it has to be noted again that the applied reduction factors are not based on empirical data from the region and therefore the model results have a high uncertainty. Since various studies stress that irreversible degradation is a problem in Mediterranean grazing systems (Ibanez et al., 2007; Köchy et al., 2008), there is the demand for empirical research on the mechanistic and temporal dynamics of these degradation effects. The results will help to further improve the explanatory power of our model.

A comprehensive validation of the applied land-use model was beyond the scope of this paper. Our efforts to evaluate the model performance concentrate on the newly implemented “Livestock” sub-model and compare the simulated area of grazing land in the three countries of our study region against statistical data for permanent meadows and pastures from FAO statistics (Fig. 7). For the base year 2000, the results show low agreement. This is due to the fact that the base year allocation step is used to initialize the spatial distribution of stocking rates by applying the unadjusted landscape productivity values from WADISCAPE (see 2.5). Consequently, all simulation runs generate the same spatial extent for grazing land. For the year 2005, the agreement between simulation results and FAO data is much higher, especially for the simulation run assuming sustainable grazing land management, but still LandSHIFT.R underestimates the area of grazing land compared to the FAO data. One reason for that mismatch is that our study only considers sheep and goats for which grazing is often executed on (semi-)natural vegetation instead on permanent pasture (Perevolotsky and Landau, 1992). As a consequence, the data for permanent meadows and pasture can be only a rough estimate of the actual grazing area for these animals. Another source of uncertainty is the assumption on the fraction of grazing at the feed composition that was set to 40% according to Nordblom et al. (1997).

In our study, we successfully apply the LandSHIFT.R model to integrate human and environmental key processes of the land-use system and to combine information on land-use (about grassland management) with satellite derived land-cover data of our study region. Nevertheless, the model is still a simplistic look on the real-world system as important processes such as rural–urban migration or the effects of additional requirements for feedstock production from unmet the feed demand on the regional extent of cropland or on international trade patterns are not included. Another limitation of our model approach is that soil processes that play an important role for degradation processes are not explicitly modeled (Ibanez et al., 2007). Regarding the modeling of feedback mechanisms, the temporal resolution of the model also becomes important. Currently, we assume that the decisions making for the allocation of stocking rates is done in 5-year time steps. In-between these intervals the grazing management is assumed constant. Further research should analyze the influence of changes in temporal resolution on the model results.

7. Conclusions

Result of our ongoing work is a new sub-module for the LandSHIFT.R model that allows simulating feedback effects between human decision making (in form of grazing strategies) and the productivity of grazing systems. In a first simulation experiment we could demonstrate that this type of feedback has a strong effect on the simulated land-use pattern and the spatial extent of grazing land. Based on these results, our research efforts will concentrate on the further refinement of the modelled decision making processes, model validation and on the conception of a more detailed and integrative study design. This includes the assessment of impacts of stocking intensities on biodiversity as well as the incorporation of more empirical data on degradation processes caused by grazing when they become available.

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