Appendix 1

Modeling Social-Ecological Feedback Effects in the Implementation of Payments for Environmental Services in Pasture-Woodlands

ODD PROTOCOL FOR ALUAM-AB

Purpose

The purpose of ALUAM-AB is to understand agricultural land-use changes triggered by market and policy changes giving due considering to the individual preferences of the farmers. The consequences of changes in prices and policy measures relating to agricultural land-use activities can be simulated. With respect to this study, spatially explicit information on agricultural activities (spatially explicit stock density change) allows for a viable linkage with the vegetation model WoodPaM.

State variables and scale

Agents represent individual farms. A farm agent has (1) its own state which is updated after every simulation period of one year and (2) decision-making mechanisms for managing farm resources. The state of the farm agent includes variables for household composition and available resources (land, capital and labor) and household preferences for agricultural activities. Information on preferences for agricultural activities, household composition and available resources was compiled in individual interviews with the farmers (see Table A2). Important parameters with respect to the individual characteristics of the farmers are: the point in time of their retirement (65 years), whether or not they have a successor (succession), their intention to increase farm size (growth), their willingness to take part in agri-environmental schemes (extensification), their preferences concerning specific production activities e.g. milk production is preferred to meat production despite lower income (activity change), and their demand for leisure time (result from the questionnaire's comment section). The interviews also allowed for the identification of the mosaic of paddocks per farm and in the whole case study region.

The smallest landscape unit in ALUAM-AB is the paddock as it is used by the individual farmer. A higher resolution of the model would not provide additional information since land-use activities are homogenous on these paddocks and the representation of vegetation dynamics in WoodPaM would not be improved. Since WoodPaM models vegetation on a higher spatial resolution of 25m^{2,} these parcels are aggregated to the level of the current paddocks for a transfer between the models. In contrast, with a lower resolution (e.g. at farm level) important information with respect to land-use intensity would be lost.

Natural conditions of the different paddocks and potential fodder production are integrated using results of the vegetation model WoodPaM. In WoodPaM, a paddock is represented by an arrangement of square grid cells, each 25 m wide. Each cell features four compartments: i) the herb layer (consisting of four ecological community types: eutrophic pastureland, oligotrophic pastureland, fallow and understory), ii) shrubs, iii) trees (13 species, divided into four life stages: seedlings, saplings, small trees and big mature trees), iv) cattle. Local succession in the herb layer is driven by local intensity of grazing, trampling, dunging and shading. Local woody plant succession is driven by seeding input, safe-site availability in the herb layer and browsing intensity. Local successions within cells are influenced by neighboring cells through seed dispersal from trees (von Neumann connectivity) and are connected at paddock level by cattle behavior. Selective habitat use by cattle among cells within each paddock considers the attractiveness of each cell, which depends on local forage production, distance to watering points, tree cover and geomorphology. The following land and soil characteristics are used as input for each paddock: altitude, slope, aspect, rock outcrops, soil depth, carbon and nutrient cycling rates, past and current vegetation, climatic data and scenarios based on observed data from 1901 to 2000 (interpolated monthly temperature and precipitation) and expected driving parameters according to IPCC scenarios.

Agronomic variables include yield losses, plant nutrient requirements (N, P), manure production and production coefficients such as fodder intake, growth, birth, deaths of animals, or labor requirements etc. that are based on Swiss average data (Briner et al. 2012). Production related variables, e.g. the number of livestock or the amount of hay sold, are aggregated at farm level and represent aggregated values over one year. In the optimization process, these variables are optimized under the consideration of different balances that link land-use activities with livestock activities: fodder and nutrient balances. As a result, land-use intensities are defined in a spatially explicit manner.

Given the focus on individual farmers, the temporal scale of the model is limited to 15-25 years in our approach. Scenario parameters for prices and costs were derived from project-based context scenarios. These are consistent with the base assumptions of the existing set of global greenhouse gas emission scenarios (IPCC SRES) and thus with the climate simulation data used for model-based impact assessment (Walz et al. 2012). The effective data followed the development presented in Abildtrup et al. (2006).

Process overview and scheduling

ALUAM-AB proceeds in annual time steps. The agents allocate their available resources in order to maximize their income (aggregated land rent from the specific paddocks). Thereby they consider natural, farm level and individual constraints as well as incentives and regulations from the market and policy instruments. Investments in production capacity made in previous years are considered as sunk costs representing path dependencies on the individual farms.

Structural change is modeled using a land market sub-model based on Lauber (2006a). The model determines paddocks that are no longer cultivated under the existing farm structure. There are 3 main reasons why paddocks are attributed to the land-market: i) paddocks generate a land rent below zero, ii) the corresponding owner of the farm does not reach a minimum wage of 30'000 Swiss Francs per year, therefore the farm is abandoned and all the assigned land enters the land market or iii) the farmer retires in the simulation year and has no successor, thus all his land goes onto the market (Figure A1).

The land market sub-model randomly assigns the paddocks to one of the other farms. It is then checked to confirm that this farm shows the two following characteristics: the farmer receiving the paddock must want to expand his cultivated area (willingness to grow) and his shadow price for the land must be positive. If these conditions are not met, the paddock is returned to the land market and assigned randomly to another farm. Once again it is checked to verify that this farm fulfils the conditions for the assignment of the paddock. This procedure is repeated until all the paddocks are assigned to a farm or none of the farms is willing to take the paddocks left on the market. Paddocks that are not transferred to other farms are defined as abandoned. Natural vegetation dynamics get under way on these paddocks (explicitly modeled in WoodPaM). If land-use allocation at farm level is optimal (both from an economic and individual perspective), farm equipment, capacities and livestock are updated and the next annual time step is initialized using the parameters (prices, costs) of the following year. In this step, the modifications due to climatic and management changes calculated in WoodPaM are used to update the spatially explicit yield potential in ALUAM-AB.

The interaction between ALUAM-AB and WoodPaM is modeled in the following sequence: while each model is driven by (synchronized) time series of climate or agronomic constraints, farm structural change is passed from ALUAM-AB to WoodPaM in terms of stocking density per paddock and vegetation response is transferred from WoodPaM to ALUAM-AB in terms of forage productivity of the paddocks. This data exchange occurs for time steps of 5 years, starting in the year 2000.

This means there is a time lag in model coupling, according to the following protocol: during each 5 year period, ALUAM-AB uses the average annual forage production of paddocks, as simulated by WoodPaM during the preceding period, to simulate yearly livestock allocation per paddock for 5 years, giving due consideration to contemporary socio-economic constraints of farms, but with temporally constant forage productivity. After that, WoodPaM uses the yearly time series of stocking densities per paddock and simulates vegetation response, from which the average productivity of paddocks during the current period is calculated, giving due consideration to climatic variability. Productivity is transferred back to ALUAM-AB as the input variable for the following 5-years-period, thus closing the local feedback loop.

We follow this protocol from 2000 until 2034, where reliable predictions of agronomic developments end. Since ALUAM-AB is based on the characteristics of the current farmers, the model is discontinued in 2034. However, given the large temporal gap between the establishment of tree seedlings and the formation of forest stands, the combined effects of land- use and climate on landscape structure can only be shown in a timeframe of at least a few tree generations. Thus, we prolong WoodPaM simulations until the end of currently available projections for climate change (i.e. 2100), assuming that land-use intensity simulated for year 2034 will be constant until 2100. These exploratory simulations pinpoint the potential, long-term consequences of today's land-use decisions.

Design concepts

Emergence
Structural change on farm level emerges from an endogenous development that is determined by prices, policies and individual preferences which are given exogenously. In addition, land-use patterns (intensity levels of land-use) emerge from the main outcome of the structural changes on farm level.

Adaptation
Farmers respond to climatic, socio-economic and policy changes by adjusting their production activities, applying new production technologies, increasing (or reducing) land size and adjusting land-use intensities. In addition, farmers also exit the sector if their income falls below a certain limit (30'000 Swiss Francs).

Objectives and prediction
The agent's objectives are characterized by a whole farm income optimization approach that governs the allocation of an agent's available resources to production considering natural, farm-level and individual constraints as well as incentives and regulations from the market (yearly price and cost parameters) and policy scenarios. Thus, the fundamental concept behind our approach is rational economic behavior (land rent maximization). However, the consideration of individual constraints, such as personal preferences and attitudes towards production activities and individual expectations concerning leisure time and well-being, leads to the inclusion of non-economic goals in the decision-making process (Lauber 2006a, b).

Agent-environment interaction and observation
The interaction between the farmers and the environment is based on the model linkage of WoodPaM and ALUAM-AB. Detailed information on spatially explicit natural conditions (e.g. grassland yields) are provided by the WoodPaM model (Gillet 2008, Peringer et al. 2012).The corresponding maps are used as an input for ALUAM-AB. The spatially explicit information following the optimization procedure is then re-entered into the vegetation model. These maps can be used to illustrate the changes in land-use dynamics.

Initialization
Initial attributes for households were defined using information from the interviews along with farm census data of the FOAG. In addition, the modeling results from WoodPaM were used to calibrate existing land-use intensities on paddock level. The corresponding results were verified with local experts (Chételat et al. 2012). The validation of the ALUAM-AB model showed satisfying results with respect to livestock numbers, farm structures and income.

Input
Information with respect to natural conditions is derived from the WoodPaM model. Price and cost developments are derived from scenarios for the European agricultural sector (Abildtrup et al. 2006). Policy and climate changes follow from an interdisciplinary development of scenarios for our case study region (Walz et al. 2012).

Sub-models
ALUAM-AB consists of individual farms which are modeled again using different sub-models for plant activities and livestock activities. A detailed description of these sub-models can be found in Briner et al. 2012. The summary of ALUAM-AB sub-models is shown in Table A1.

Link to OpenABM
http://www.openabm.org/model/2870/version/2/view

Literature cited

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Figure A1: Process of farm structural change in ALUAM-AB

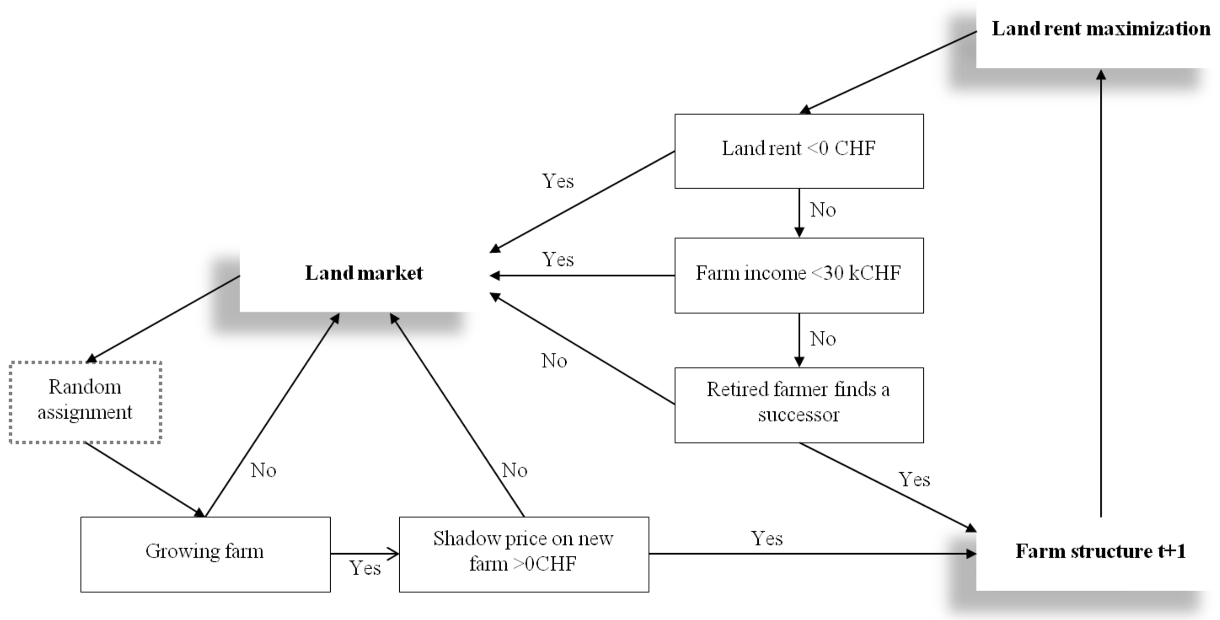

Table A1: Short description of the ALUAM-AB sub-models

Sub-model	Agent or natural object/system involved	Function
Plant production sub-model	Agricultural land- use activities	Represents fodder and crop production systems. Reconciles natural plant development (yields, nutrient input, etc.), farm technology (harvest technology, labor, etc.) and resulting returns and costs per output unit (kg of crop).
Livestock sub-model	Livestock activities	Represents the livestock production system on farm level. Calculation of in- and output for different livestock activities including dairy and suckler cows, calves, cattle and others. Considers production inputs and farm technology (including labor) as well as farm structures (buildings). Returns and costs per output unit (milk, meat) are calculated.
Integrating agronomic sub-model	Agricultural activities	Balances the supply and demand for roughage and nutrients on farm level; links the livestock with the plant production sub-model.
Agent decision sub-model	Farm agents	The decision of the different agents is based on a constrained income maximization organized in an objective function and a set of constraints which define the solution space formally written as $Z = \sum_j (p_j - c_j) \cdot x_j$; $\sum_j a_{ij} \cdot x_j \le b_i \quad \forall i = 1 \ldots I$; $x_j \ge 0 \quad \forall j = 1 \ldots J$ Z= income per farmer x_j= agricultural farm activity (j=1 to I) p_j= returns of activity j c_j= cost per activity j a_{ij}= technical coefficients required to produce x_j (of constraint i and activity j) b_{ij}= available resource All activities x_j are non-negative. Individual resource constraints (b_{ij}) are defined for each agent based on Table A2. E.g. if the farmer stated that leisure time is an objective, the availability of work was a constraint in the corresponding agent.
Environmental sub-models	Agricultural activities	Calculations of nitrogen (N) and greenhouse gas (GHG) emissions based on coefficients for each activity.
Land market sub-model	Land units (paddocks)	Distributes abandoned land among the remaining farms (see Figure A1). Agents are limited to farm expansion if the farmer is unwilling to increase farm size.
WoodPAM (optional)	Land units (paddocks)	Calculates spatially explicit fodder yields in the different paddocks based on i) current land-use, ii) natural site conditions (soil and climate) and iii) stocking density. Yields are integrated via the plant sub-model.

Table A2: Characteristics of farms in 2011

Name	Les Planets Ouest	Les Planets Milieu Ouest	Les Planets Milieu Est	Les Planets Est	Les Cluds Sud	Les Cluds Nord	La Bullatone Dessous
Farm size (ha)	65	31	32	49	60	55	47
Number of cows	33	16	20	26	40	18	47
Free capacity (GVE)	No	No	4	12	10	-	No
Milk (kg/year)	226’000	103’000	135’000	149’000	-	-	310’000
Meat production					Suckler cows	Fattening Calves	
Breeding (number of cattle)	No	Yes (8)	Yes (10)	Yes (13)	No	Yes	Yes (15)
Summering	No	Yes (breeding)	Yes (breeding)	Yes (breeding)	15 suckler cows	Yes	Yes (all dairy cows)
Other animals (number)	No	No	No	Bull fattening (5)	13 horses	Calf fattening	Bull fattening (20)
Age of farmer (years)	50	53	61	42	31	38	40
Additional workforce	Wife (50%)	Wife (50%)	Wife (50%)	Wife (30%)	Wife (50%) Apprentice	-	Wife (10%) Brother (100%)
Work outside agriculture	No	No	No	Yes (30%)	Yes (40%)	-	Yes (20%)
Extensification	Yes	Yes	No	No (no direct payment optimization)	Yes (even organic)	Is already organic	No
Activity change	No	No	No	Yes	No	No	No, only milk
Growth	No growth in milk production, no land claims	No land claims	No growth in milk production, no land claims	Milk and land if possible	No more animals but land claims if close to farm	No	Conditional (investment and quality of soil)
Succession	No	No	No	(retired in 2034)	(retired in 2045)	No	(retired in 2032) Sons are interested
Comments	Leisure time as objective	Ecology is important (without label)	No future	Leisure time as objective	Leisure time as objective	-	-