Appendix 1. ODD protocol (Grimm et al. 2006) of ALUAM-AB

Purpose. The purpose of the Agent-Based Alpine Land Use Allocation Model (ALUAM-AB) is to simulate the effect of socio-economic, climatic and political pressures on farm structure and emerging land-use changes in mountain landscapes.

State variables. Agents represent groups of farmers. An agent has (1) its own state (i.e., land endowment, stable capacity, etc.) which is updated after each yearly simulation period and (2) its own decision-making mechanisms for managing farm resources in form of constraints to an income optimization approach. Agent typologies were derived from interviews with and a survey among local farmers and from an analysis of agricultural census data. Fourteen agent types were derived from the farm survey using a PCA with a quartimax rotation and subsequent k-means clustering on 19 farmers' characteristics, which included the opportunity costs of labor, additional workforce hired, a threshold for minimum income, farm size, the intention to increase farm size or livestock housing capacity (details are given in Brändle et al. 2015). The median characteristics for each agent were then fed into the model (Table A1).

Scale. The smallest landscape unit is one hectare. The size of the study is 44 330 ha, of which 12 163 ha were used in the simulations. The model was run between 2001 and 2010.

Process overview and scheduling. ALUAM-AB proceeds in annual time steps. The agents allocate their available resources to maximize their income. Thereby they consider spatially-explicit natural, farm level and individual constraints as well as incentives and regulations from the market and policy instruments, which are annual input data to the model. Investments in production capacity made in previous years are considered as sunk costs representing path dependencies of the individual agents. Structural change is modeled using a land market module (Lauber 2006; Huber et al. 2013). The module identifies land units that are no longer cultivated under the existing farm structure due to negative land rents, because an agent does not reach the minimum wage level or if farmers retire without successor. The land market module randomly assigns the land units to one of the other agents and then checks whether the shadow price for the land unit is positive. This procedure is repeated until all land units are assigned to an agent or until no more agents are willing to take the land units left on the market. In that latter case, they are regarded as abandoned land and subject to natural vegetation dynamics. When land-use allocation is optimal, farm capacities and livestock, as well as the age of the agents are updated and the next annual time step is initialized.

Emergence. Changes in the activities of agents emerge from changes in prices, policies and the climate (see below scenarios) and depend on the decision-making type. In addition, land-use patterns emerge from structural changes at the agent level and from spatially explicit climate-induced changes of yield quantities.

Adaptation. Agents respond to external pressures by adjusting their production activities, applying new production technologies (e.g. irrigation), increasing (or reducing) land size and adjusting land-use intensities. In addition, agents exit the sector if their income falls below a minimum threshold.

Prediction. The model follows an income optimization approach assuming rational economic behavior with no direct learning pattern. However, the consideration of individual constraints, such as opportunity costs, minimum income wage and limited time resources, includes non-economic goals in the decision-making process.

Interaction. The interaction between agents is based on the land market described above. Interaction between agents and the environment is based on the model linkage with a sub-model *LandClim*, which is a spatially-explicit process-based model that simulates forest dynamics and yields on meadows given different management regimes (Schumacher and Bugmann 2006).

Initialization. Initial attributes for agents were chosen randomly. This includes the age structure of each agent, the number of farmers in each agent and the allocation of land units to agents.

Input. Spatially-explicit data were derived from national data sets (Swisstopo 2005; FOAG 2008; SFSO 2009) or simulated with *LandClim*. In the baseline setting, policy and socio-economic parameters were chosen to represent the local conditions in 2001 (Briner et al. 2012; Huber et al. 2014).

Calibration and validation. ALUAM-AB was validated against observed livestock and land-use data between 2001 and 2013. Overall and unequal variation errors of model performance were small (on average 6.5%), thus, the model satisfactorily captured the mean and trends of the observed data (Brändle et al. 2015).

Software requirements. ALUAM-AB runs on Linear Programing Language (LPL) from Virtual Optima and requires ILOG CPLEX Optimization Studio from IBM. LPL academic license is available for purchase at http://www.virtual-optima.com/en/index.html, and CPLEX academic license is available free of change at https://www.ibm.com/software/.

Table A1. Agent types in ALUAM-AB. Farm sizes, age of the farmers and number of farms in each agent were randomized.

Agent	Opportunity costs	Available work	Min. income	Farm growth	Succession rate	Sheep	Dairy cows	Beef cattle	Suckler cows
	x 10 CHF/h	% of 2800h	CHF		in %		Number in the year 2000		
1	0.2	1	25000	Yes	0.75		237	215	
2	0.2	0.6	25000	Yes	0.75	376			
3	0.5	0.6	25000	Yes	0.75			86	43
4	0.2	0.5	10000	No	0.55		156	123	
5	0.2	0.5	10000	No	0.55		93	93	
6	0.2	0.8	10000	No	0.45	44	41	208	
7	0.2	0.5	100000	No	0.45	870			
8	0.2	0.8	10000	No	0.45	26	27	146	
9	0.5	0.5	0	No	0.45	208			
10	0.5	0.5	0	No	0.45	222			
11	1.25	0.3	0	Yes	0.55	558			
12	1	0.5	10000	Yes	0.55		38	27	
13	1	0.3	10000	No	0.55				
14	0.2	0.3	0	No	0.45	932			

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