Appendix 1 for Hanspach et al.: A holistic approach to studying social-ecological systems and its application to Southern Transylvania

Appendix Text A1.1

Local conditions

We assessed local conditions in terms of natural capital and socio-economic conditions in the study area (Table A1.1). For an in-depth understanding, we initially analyzed a subset of 30 randomly selected villages (Fig. A1.1).

First, we characterized these villages with respect to their natural capital and statistically classified them into three groups. Villages in the first group (yellow in Fig. A1.2) were characterized by high proportions of forest, orchards, high carbon stocks, high species richness, high pollinator abundance and high scenic beauty. Villages in the second group (blue in Fig. A1.2) were characterized by a high proportion of arable land, and villages in the third group (red in Fig. A1.2) had high proportions of pasture. Based on this grouping, we concluded that village conditions could be effectively summarized by the amounts of the main land cover types (arable, pasture, forest).

Second, we described socio-economic conditions in the communes that the target villages belonged to. We used data from the commune level because socio-economic data were not available at the level of individual villages. Because some villages belonged to the same communes, this analysis was restricted to data from 22 communes. Again, we statistically classified the communes according to their characteristics and found two major groups of communes. Communes belonging to the first group (light blue in Fig. A1.3) were characterized by a high proportion of Romanians, few Hungarians, and relatively high emigration rates, whereas communes from the second group (orange in Fig. A1.3) had a high proportion of Hungarians, few Romanians, and relatively high immigration rates. Notably, the cluster analysis did not pick up the gradient that was described by the second ordination axis in Fig. A1.3. This second gradient related to unemployment rate, proportion of pupils and proportion of Roma. Because the plight and influence of ethnic Roma were frequently discussed by stakeholders as important socio-economic variables, we considered the proportion of Roma in a village in subsequent analyses.

In summary, we used the proportion of forest, arable land and pasture to summarize natural capital bundles characteristic of different villages; and we used the proportions of Hungarians and Roma to summarize socio-economic conditions of different villages. In both cases, these variables were derived from detailed data obtained for a subset of villages, but

the resulting general variables were subsequently used to characterize conditions in all villages throughout the study area.

Full scenario narratives

Scenario 1: "Prosperity through growth"

European Union (EU) incentives and global markets have created a favorable business environment. Demand is high for conventionally produced agricultural and forest products. National policies are strongly favoring economic development, including in rural areas.

Drawing on the natural capital available, local entrepreneurs (and a small number of foreigners) are using this institutional setting to take advantage of business opportunities, and partnerships between Western European and Romanian companies are common. Both farmland and forests are being used intensively wherever the landscape allows it, including the use of fertilizers and irrigation of farmland. The scenic beauty of the landscape suffers as a result, but plenty of money is flowing from commodities such as fuel and food crops, as well as wood.

Although the incomes of most people are modest compared to those running the new businesses, economic development has improved the region's overall material well-being. The education system also has improved, and there are many opportunities to obtain vocational training.

Tourism is centered on cultural heritage sites and newly emerging fun parks. Neither the natural environment nor traditional festivals contribute significantly to the tourism sector.

Land use intensification has caused the loss of biodiversity throughout the landscape, including the local extinction of several species of conservation concern. The water from local fountains is no longer safe for consumption, but people are largely indifferent to this because, unlike in the past, their houses are now connected to running water. Intensive forestry has left some hilltops without trees. As a result, runoff events are more intense than they used to be, causing the erosion of slopes and occasional floods.

Conflicts in the communities are less pronounced than earlier in the millennium, largely because fewer people suffer from poverty. Although individualism is more notable than in the past, community spirit has increased in many villages due to improved material conditions. Corruption levels have decreased, but doubts remain about the inner workings of some of the most successful farm businesses.

In aggregate terms, people in the region are better off than at the beginning of the millennium – but improvements to aggregate welfare have not reached everybody equally, and natural capital has paid a high price.

Scenario 2: "Our land, their wealth"

The business environment in Europe is very favorable: There is high demand both for agricultural and forest products, as well as for tourism. However, local conditions in Southern Transylvania are in stark contrast to the larger-scale context. For decades, Southern Transylvania has been trapped in conditions of community fragmentation, poor infrastructure, and corruption.

Owing to low social capital and poverty, the people in Southern Transylvania are unable to capitalize on the opportunities provided by global market settings. Both national and local governments are failing to support the development of markets and necessary infrastructure that would benefit smallholder farmers. Yet, the region's natural capital does not go entirely unnoticed: Romanians from outside Transylvania and foreigners increasingly move into the area to set up large businesses focusing on forestry and agriculture. Where regulations stand in the way of development, corruption usually finds a way around these obstacles – as a result, forest exploitation is now characterized by intensive clearcuts, and industrial-style farms controlled by foreign companies occupy most of the larger valleys (referred to as "land grabbing" by some locals).

In some remote villages, land use has not intensified. In some locations, subsistence agriculture continues to exist, and some locals have found viable economic niches to produce specialty products such as goat cheese and honey. In other locations, much of the land has been abandoned. Regrowth forest is expanding into these areas.

Tourism has mostly disappeared, or it is controlled by foreigners. Most of the cultural heritage is in poor shape, and natural heritage is rapidly deteriorating. Whoever is capable of leaving the region – even for poorly paid seasonal work in other countries – does not hesitate to go. The people remaining are mainly the elderly and the very poor, including many Roma. Community spirit is declining and many traditional cultural values are being lost.

While ecosystems were once rich in biodiversity, many species have declined over the last few decades. Only the most remote villages still feature the species that Transylvania once was famous for among naturalists. With deteriorating ecosystem integrity, many of nature's services have also taken a heavy toll – for example, fountain water is no longer safe for

consumption, some of the steeper logged areas are rapidly eroding, and intense runoff after heavy rainfall occasionally causes flooding.

Overall, local people have suffered and the traditional landscape character has been lost. Only few individuals, mostly from outside the local area, have benefited from the developments.

Scenario 3: "Balance brings beauty"

Demand for environmentally friendly practices was already high in Western Europe, when in 2020, France narrowly avoided a major nuclear accident. This event precipitated rapid political changes throughout the European Union (EU). Social justice and ecological sustainability were adopted as guiding principles underpinning all EU regulations. Unlike its predecessor, the latest reform of the Common Agricultural Policy brought about fundamental changes, and is considered worldwide as a milestone towards sustainable development. Subsidies are now strongly focused on organic farming, available only to associations of farmers who can demonstrate a holistic, landscape-scale vision for sustainable resource use.

Romania's education system improved substantially over the past few decades, enabling many locals in southern Transylvania to access the new EU subsidies for sustainable farming. Farms continue to be relatively small, but almost all farmers are now part of agricultural associations and practice modern organic farming, growing a variety of crops.

The forestry sector has also changed. Demand for wood products is high, but the majority of Romania's forestry sector is based on sustainable, low-intensity harvesting. Moreover, forest regrowth rates have increased substantially. While few forested areas remain untouched, Romania's forest estate is managed according to the best available science.

Farmland and forest biodiversity initially declined when land use was upgraded to modern organic practices, but the losses were relatively minor. Water from the fountains is just as clean as it was decades ago, and continues to be favored as the cheapest source of drinking water in many villages.

A vibrant rural tourism industry has developed in the most scenic villages. Guesthouses are common, as are cafes and traditional festivals. Local people are proud that their cultural and natural heritage is attracting tourists from all over Europe.

Few people in the region are rich in monetary terms, but hardly anybody is suffering from poverty. People coped well with the recent drought, and are largely immune to the fluctuations in agricultural commodity prices that recently shook many farmers in Western

Europe. Ethnic divides have all but disappeared, partly aided by common visits by foreigners and increasing openness towards different cultures. A healthy service industry is developing in addition to the most important income sectors, namely agriculture, forestry and tourism. While many young locals leave the region for a while, many of them come back because they are attracted by the lifestyle and scenic beauty in their home region.

Scenario 4: "Missed opportunity"

The latest reform of the Common Agricultural Policy provides major subsidies for organic farming across Europe. Minimum size requirements of agricultural parcels can be met by forming farmer associations.

However, only few communities are able to capitalize on this opportunity, despite all relevant information being readily available via standard technologies such as the internet. Many villages are caught up in a vicious cycle of poverty, conflict and corruption. In these villages, a long history of mistrust, conflict, and crime stands in the way of the formation of farmer associations.

Yet, the productive soils and ready availability of cheap labor do not go unnoticed internationally. Increasingly, western European entrepreneurs see opportunities in being able to buy Transylvanian land and start large organic farm businesses, drawing on substantial EU subsidies in the process. These farms create some employment opportunities for local villagers, but primarily favor skilled workers who are able to operate modern machinery. To meet this demand for skilled labor, vocational training opportunities have increased.

Under new EU regulations, large parts of the forest estate are formally protected. Commercial forestry operations are led by a small number of international companies. Anti-logging regulations are being actively enforced in large parts of Southern Transylvania, but some illegal logging continues – driven by corrupt local governments turning a blind eye to illegal operations, and by locals who prefer to take a risk rather than pay for their firewood.

The population of Southern Transylvania is declining. Many remote villages are almost entirely abandoned, or comprise only poor households practicing subsistence agriculture. Around abandoned villages, pastures are overgrowing and turning into regrowth forest.

Farmland biodiversity is declining where large organic farms have simplified the landscape. However, in less suitable areas, subsistence agriculture remains and continues to provide a stronghold for farmland species that are threatened with extinction elsewhere in Europe. If it was not for the free services provided by nature – clean water and plenty of food – many

Transylvanians would be in serious trouble. As it stands, many are poor, but not lacking the essentials they need for survival.
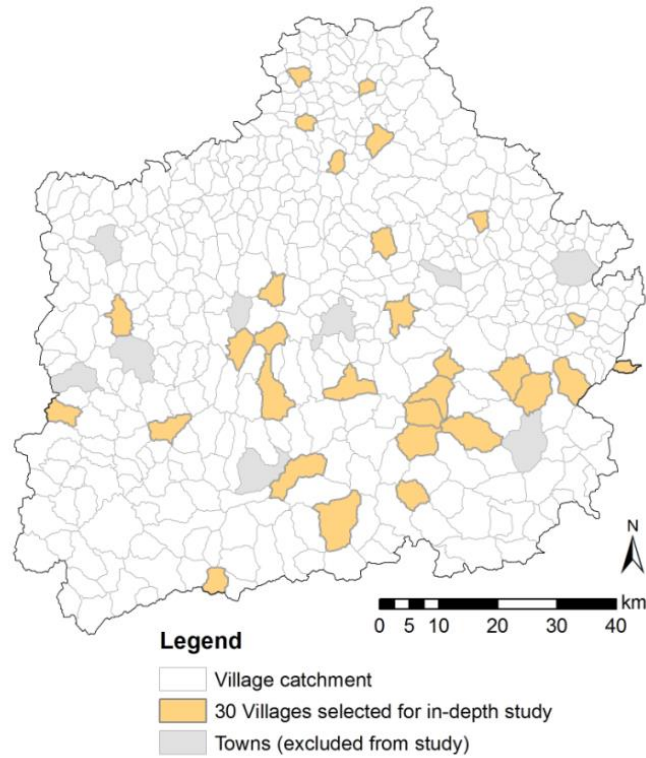
Appendix Fig. A1.1. A subset of 30 villages was selected for in-depth characterization of local village conditions. Villages were chosen randomly within pre-defined strata relating to their protection status under EU Natura 2000 regulations and terrain ruggedness.
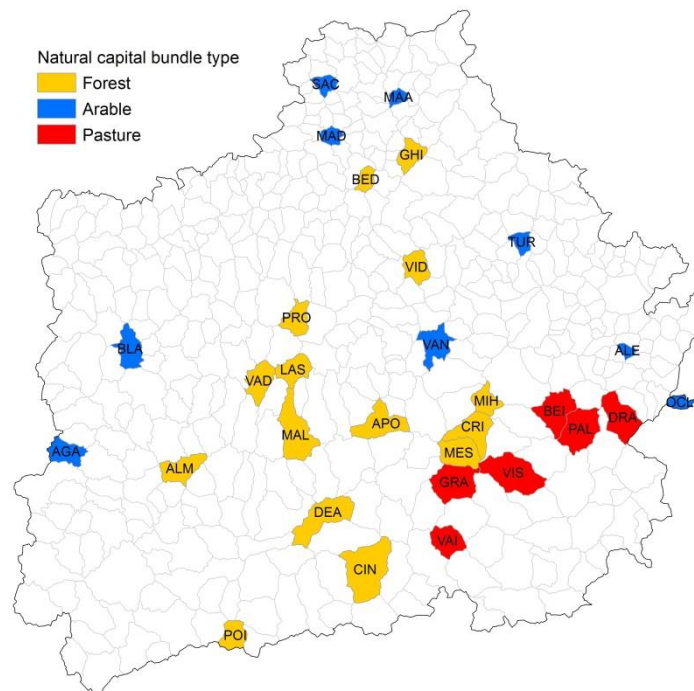
Appendix Fig. A1.2. Statistical classification of the 30 focal villages according to their natural capital assets. The three village types (forest – yellow, arable - blue, pasture - red) were derived from agglomerative cluster analysis (see Fig. 3).
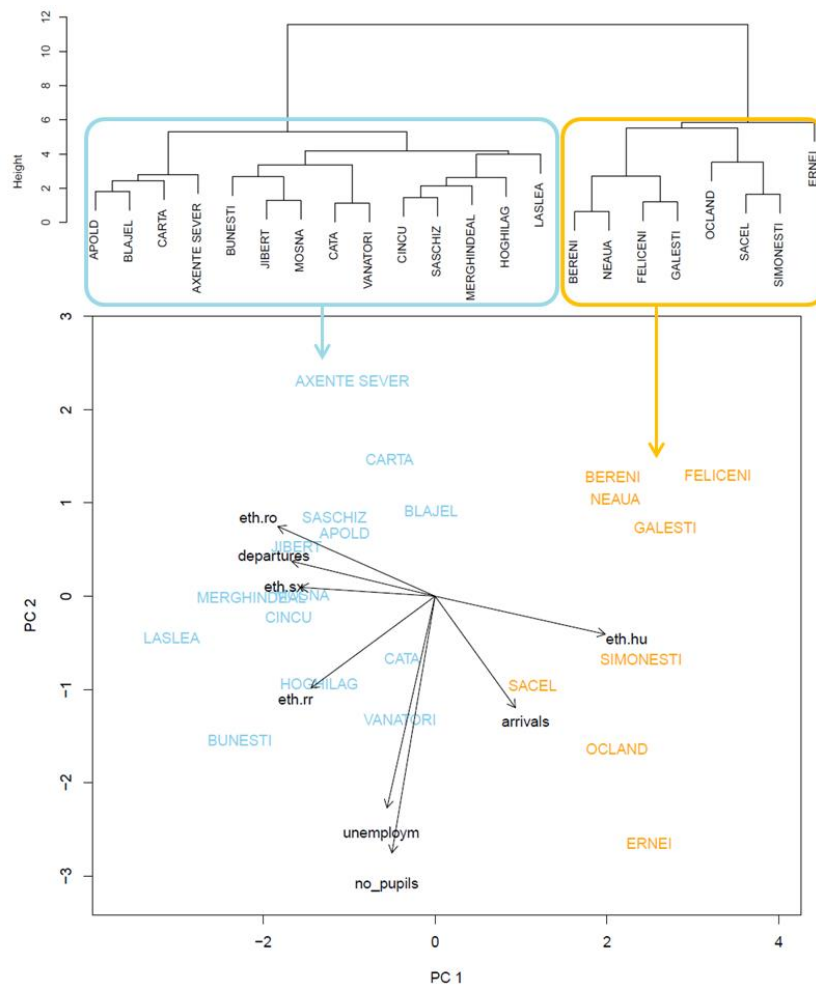
Appendix Fig. A1.3. Structure of demographic and socio-economic data of the 22 communes in which the 30 focal villages were located. The figure shows the results of an agglomerative cluster analysis (upper panel; Wards method on Euclidean distances; agglomerative coefficient: 0.83) and a centered principal components analysis (lower panel; all variables scaled; explained variance of the first axis: 46 %; and of the second axis: 19 %). Two main groups of villages, relating to dominant ethnicity, are apparent. (Abbreviations: eth.ro – proportion of Romanians [%]; eth.hu – proportion of Hungarians [%]; eth.rr – proportion of Roma [%]; eth.sx – proportion of Saxons [%]; unemploym – unemployment rate; no_pupils – number of pupils; arrivals – number of people arriving relative to total number of people in a commune; departures – number of people departing relative to total number of people in a commune)

Appendix Table A1.1. List and detailed description of variables used to describe local characteristics. Asterisks indicate variables that were assessed for the whole study area. All other variables were additionally used for an in-depth description of the random subset of 30 villages.

Ecological variables	Description
Arable*	Proportion of arable land (all non-permanent crops according to Corine 2006 Land Cover Map (EEA 2006)) relative to total village area as a proxy for the potential to generate food and other agricultural products
Pasture*	Proportion of pastures according to Corine 2006 relative to total village area as a proxy for the potential to generate milk, cheese, meat, and wool
Forest*	Proportion of forest according to Corine 2006 relative to total village area as a proxy for the potential to obtain timber, firewood and non-timber products, but also non-provisioning services like flood protection and water purification
Orchards	Proportion of orchards according to Corine 2006 relative to total village area as a proxy for the potential to grow fruit
Scenic beauty	Expressed as a village ranking based on a scoring system that was informed by our personal experience in the field and stakeholder discussions. The score of a given village was the sum of individual scores derived from forest cover (village belongs to the lower tercile, i.e. has low forest cover: -1; village belongs to the upper tercile, i.e. has a high forest cover: +1), terrain ruggedness (lower tercile: -1, upper tercile: +1), landscape heterogeneity (lower tercile: -1, upper tercile: +1), presence of fortified churches or castles (+1) and the presence of major roads (-1).
Hunting	To estimate utility as a hunting area, we extracted the estimated population sizes of red deer, roe deer, boar and hare between 2001 and 2010 from official sources (http://www.mmediu.ro/paduri/vanatoare.htm), normalized the data to unit area and ranked the villages according to the relative total count of hunted individuals per unit area
Carbon stocks	Carbon stocks were derived by calculating an average amount of carbon (aboveground, belowground, soil) per ha and per land cover type (arable, pasture, forest) and subsequently calculating the total carbon stock per catchment. Information on carbon concentration was derived from the IPCC (IPCC 2006).
Farmland biodiversity	Farmland biodiversity was estimated as the number of plant, butterfly, and bird species in 1 ha grid cells in the farmland of each village catchment based on field data, and was then averaged to the village catchment. The estimate per grid cell was based on field surveys in 120 circular 1 ha sites (2 sites in pasture and 2 in arable in each of the 30 villages) during spring and summer of 2012. Within a given village catchment, survey sites were chosen using stratified random selection. Stratification was performed by fully covering gradients in landscape heterogeneity (measured as the variation in the panchromatic channel of SPOT 5 satellite imagery

	(CNES 2007, Distribution Spot Image SA) in a 1 ha circle) and amount of woody vegetation (derived by a supervised classifications of the monochromatic channels of SPOT 5 data using a support vector machine algorithm, Huang et al. 2002). Plant surveys were conducted in spring/summer 2012 using eight randomly selected 1 m^2 squares within each 1 ha site, and noting all present species. Butterfly richness was estimated by conducting four standard Pollard walks (Pollard & Yates 1993) of 50 m length within a given site, repeated at four different times during spring/summer 2012. Bird richness was estimated by conducting three 10 min point counts within each site in spring 2012. All singing males were recorded. The richness estimates thus obtained for each of 120 sites for each group were modelled in response to percent woody vegetation and heterogeneity within the site as predictor variables in linear models (using linear and quadratic terms as predictors). Based on these models we predicted the richness of the different groups for the whole farmland area of the catchments, excluding areas outside of the calibration range of the independent variables. We calculated the averaged richness for each taxonomic group for each of the 30 village catchments. Finally, to visualize the relative level of farmland biodiversity in a given village, we ranked villages according to their average rank of the richness in each of the three groups.
Pollinator abundance	Pollinator abundance was assessed by counting pollinating insects in 2 m wide and 200 m long transects within a subset of 76 of the 120 1 ha sites described above. Each site was sampled three times for 20 min periods between May and July 2012. The total number of individuals from all relevant groups of pollinators (honeybees, wild bees, bumblebees, hoverflies, and butterflies) was modelled as for biodiversity to obtain an index of pollinator abundance for each village catchment.
Social variables	**Description**
Ethnic groups*	Proportion of the main ethnic groups (Romanians, Hungarians, Roma and Saxons) relative to the total population in a given commune in 2010 as derived from the National Institute for Statistics (Institutul Național de Statistică; data received 6 February 2012).
Unemployment rate	Proportion of people unemployed relative to the total population in a given commune in 2010 (source: see ethnic groups)
Arrivals	Proportion of people arriving in a given commune between 1995 and 2005 relative to the total population in a given commune in 2010 (source same as ethnic groups)
Departures	Proportion of people departing in a given commune between 2005 and 2010 relative to the total population in a given commune in 2010 (source: see ethnic groups)
Pupils	Number of registered pupils relative to the total population size in a given commune in 2010 (source: see ethnic groups)
Additional variables	**Description**
Village area*	Built up area per village catchment according to Corine 2006 Land Cover Map (EEA

	2006)
Isolation*	Isolation from the nearest town was estimated as the travel time by car to the next town with >20 000 inhabitants, distinguishing between four different types of road for all villages in the study area
Ruggedness*	Terrain ruggedness was calculated as the standard deviation of altitude from ASTER GDEM v2 within a given catchment

Appendix Table A1.2. Scores describing how variables of regional system dynamics relate to certain local village condition. Values represent reasonable and consistent trends that were mentioned in the stakeholder workshops.

Driver	Description of driver	Intensi-fication	Abandon-ment	Forest exploi-tation	Tourism	Local economy	Social capital	Emi-gration	Influence of foreigners
Proportion of Roma	high: upper third		+1	+1		-1	-1		
Proportion of Hungarians	high: upper third	+1				+1	+1		
Isolation	high	-1	+1		0	-1	+1		
	medium	0	0		+1	0	+0.5		
	low	+1	-1		0	+1	0		
Village size	small	-1	+1	0	+1	-1	+1	+1	
	medium	0	0	+0.5	+0.5	0	+0.5	+0.5	
	large	+1	-1	+1	0	+1	0	0	
Ruggedness	low	+1	-1		0		0		
	medium	0	0		+0.5		+0.5		
	high	-1	+1		+1		+1		
Proportion of arable land	high: upper third	+1				+1			+1
Proportion of pasture land	high: upper third	+1			+1				
Proportion of forest	high: upper third			+1	+1				

Appendix Table A1.3. Scores describing how trends in variables of regional system dynamics are expected to change under the four different scenarios. Values are based on the relative changes as described in the scenario narratives. Possible changes are: strong dampening (-3); intermediate dampening (-2); weak dampening (-1); no change (0); weak amplification (+1); intermediate amplification (+2); strong amplification (+3).

Scenarios	Intensification	Abandonment	Forest exploitation	Tourism	Local economy	Social capital	Emigration	Influence of foreigners
Prosperity through growth	+3	-2	+2	+1	+3	+1	+1	0
Our land, their wealth	+3	+1	+3	-2	0	-1	+3	+3
Balance brings beauty	+2	-1	-1	+2	+1	+3	-2	0
Missed opportunity	+1	+2	+1	-1	0	-1	+2	+1

References

EEA. 2006. Corine land cover 2006 - A seamless vector database. Copenhagen, European Environment Agency.

Huang, C., L. S. Davis, and J. R. G. Townshend. 2002. An assessment of support vector machines for land cover classification. *International Journal of Remote Sensing* 23(4):725-749.

IPCC. 2006. IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use. Prepared by the National Greenhouse Gas Inventories Programme. in H. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe, editors. Hayama, Japan, Institute for Global Environmental Strategies (IGES).

Pollard, E., and T. J. Yates. 1993. *Monitoring butterflies for ecology and conservation : the British butterfly monitoring scheme.* London, Chapman & Hall.