"Fingerprinting" forest-dependent communities: Linking Earth observation and household survey data for assessing sustainability and resilience

Franziska Albrecht[1], Richard Aishton[2], Andrey S. Zaytsev[2,3], Clemens Holzer[1], Konstantin Gongalsky[4], Roman Volosyanchuk[2,5], Christian Hoffmann[1]

[1] GeoVille Information Systems GmbH, Innsbruck, Austria, albrecht@geoville.com

[2] IUCN (International Union for Conservation of Nature), Gland, Switzerland

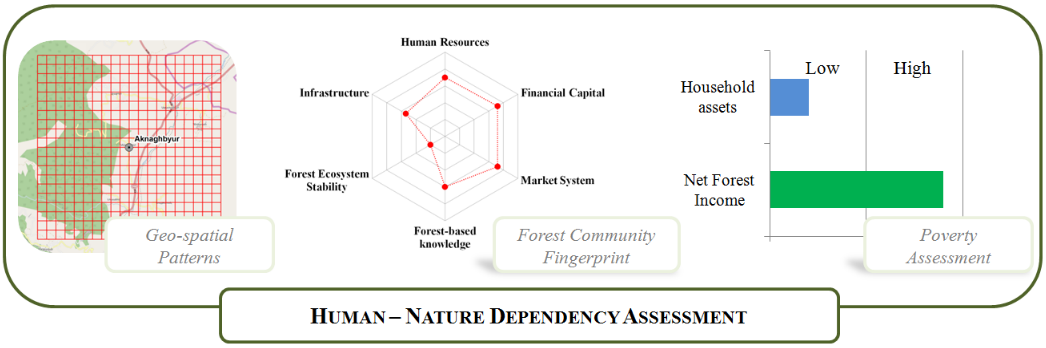
[3] Interdisciplinary Research Centre for Biosystems, Land Use and Nutrition, Justus-Liebig-University, Giessen, Germany

[4] A.N.Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, Moscow, Russia

[5] "Ekosfera" NGO, Uzhhorod, Ukraine

Abstract

The Forest Community Fingerprint (FCF) is a novel approach to more accurately estimate the human-nature dependency structure in boreal and temperate forest ecosystems and to document drivers of sustainability and efficiency of interactions between communities and their surrounding forest ecosystem resources. The FCF concept utilizes specific data gathered during targeted household surveys as well as information derived via remote sensing techniques.



Especially the latter one provides fundamental means to make assumptions about the resilience of forest-dependent communities, without the need of performing extensive field visits in each of these communities. Hence, our approach is a timesaving and cost-effective way to i) optimize investment decisions that aim in improving a communities' economic status and resilience as well as for ii) pre- verification of targeted interventions or by confirming that the investments done produced the desired results. Developed for and applied to communities located in northern temperate and boreal forest ecosystems, the FCF is a universially applicable tool, that due to its flexible character can be after some additional verification expanded to other forest ecosystems like tropical rainforests or even, after some further adaptation, non-forested ecoregions. This paper illustrates the conceptual framework of the Forest Community Fingerprint using results for 36 communities across the Eurasian northern temperate forest ecosystems.

Introduction

Covering roughly 4 billion hectare (31 %) of the earth's land surface (FAO 2010), forest ecosystems provide a myriad of functionalities and services for indigenous and rural communities worldwide. Globally, approximately 1.6 billion rural people to some extent depend on forest resources (World Bank 2001, 2004) and 350 million are entirely dependent on goods and services coming from forest ecosystems for their daily livelihoods (Chao 2012). Forest resources are considered as an important source for improving community well-being and alleviating some of the impacts of poverty (Angelsen und Wunder 2003). In fact, forest and environmental income can reduce inequity and constitute an important income source particularly for poorer households (Cavendish, 1999, Cavendish 2002, Ambrose-Oji 2003, Fisher 2004, Appiah, et al. 2009).

Along with fire wood as a principle source of energy in many forest-dependent villages, non-timber forest products (NTFP) comprise an essential basis to maintain the livelihoods in rural communities. In particular NTFPs are essential by i) supporting current consumption in lean seasons or supplementing the diet of a particular household (de Merode, Homewood und Cowlishaw 2004), ii) functioning as a safety net in times of shock or crisis, e.g. to mitigate risk for rural people living in marginal areas with high risks of crop failure (Angelsen und Wunder 2003, McSweeney 2004) and iii) providing regular cash income to the total household economy (Cavendish 2002, Chileshe 2005, Shackleton, et al. 2007, Kamanga, Vedeld und Sjaastad 2009, Heubach, et al. 2011, Angelsen, Jagger, et al. 2014). However, although cash income from forest products may contribute to accumulation of wealth, its capacity to actually pull people out of poverty is debatable (Arnold und Bird 1999, Barham und Coomes 1999, Byron und Amold 1999, Wunder 2001, Angelsen und Wunder 2003, Scherr, White und Kaimowitz 2004, Coomes 2004).

Collection of NTFPs is accessible and attractive to the poor due to low investment and skill requirement, but the same characteristics facilitate extraction by wealthier households and non-local agents, too. In many countries, especially those with transitional economy, collection of timber and NTFPs is not strictly regulated by legislation and generally is not recognized through normal taxation procedures. In fact, they are considered as common pool resources (CPR) where exclusion is nontrivial (but not necessarily impossible) and where the yield is subtractable. Hence, these resources face congestion and overuse of the resource base that ultimately lead to degradation and deforestation, with negative effects on the livelihoods of the forest-dependent poor (Neumann und Hirsch 2000, Angelsen und Wunder 2003). To counteract this downward spiral, targeted policy and management strategies are crucial. In fact, local CPR management strategies are considered as an effective measure for reducing poverty, fostering the local level economy and for biodiversity conservation (Adhikari, Di Falco und Lovett 2004). However, to effectively direct management decisions on a local scale it is essential to understand the factors interaction that lead to forest ecosystem depletion and degradation in order to define priority areas for intervention.

This paper presents a novel approach for assessing the resilience, well-being and sustainability of rural forest-dependent communities by linking ground-based survey data and information derived using remote sensing techniques. The rationale is governed by the hypothesis that there exists a strong linkage between the resilience of a community and the ecosystem profile of the surrounding landscape. Parameters describing ecosystems can be derived from satellite-based Earth Observation (EO) and other geospatial information. While EO provides a platform to analyse unknown communities, the ground-based data employs community and household information of the forest-dependent communities. The latter one holds the key to devising intervention strategies and forms the basis for monitoring change and formulating adaptive management strategies. Hence, the proposed approach will lead to much more informed and focused intervention strategies, improved understanding of the resilience and highlights some wider policy implications related to rural livelihoods. In this context, the developed framework will support sustainable and locally-appropriate forest policy measures by placing a strong emphasis on responding to the needs of national and local government policy-makers.

The Forest Community Fingerprint - Concept

The Forest Community Fingerprint (FCF) is the centrepiece of the proposed methodology. Not only does the FCF concept help to define strategic intervention targets and serves as a link for understanding the poverty-forest interaction, but it also provides a way to identify communities at risk out of a large pool of forest-dependent communities distributed over extensive landscapes.

The FCF builds upon a former approach developed by Shaanker et al. (2003), which used ecological knowledge and existing market system of a community and related both parameters to its ecological stability. The FCF concept is expanding this approach and is based on a function of six selected parameters which include 1) Human Resources, 2) Financial Capital, 3) Market System, 4) Forest-based Knowledge, 5) Forest Ecosystem Stability and 6) Infrastructure (see Figure 1). The proposed concept is more comprehensive in describing the diverse facets of a community status with respect to forest use.

Figure 1: The Forest Community Fingerprint (FCF) Concept

"Human Resources" refer to the general knowledge, education, talents, personal skills, experience, judgment and qualifications possessed individually and collectively by the community members. Indirect variables that influence the parameter are the communities' age distribution and migration rate. Hence, it reflects the social situation in the communities. "Financial Capital" is defined as all assets and income sources of the local communities measured in terms of money. This indicator reflects the economic situation of the community and is based on the various income sources of a household (e.g. income from timber, NFTP income, income from agricultural activities, etc.), the livestock as well as the household assets and other property. Further, the Gini-coefficient, a statistical measure of inequality that reflects the income distribution within a community (Sen 1997), is incorporated into the analysis as a measure of the diversity of the total household economy. The possibility of the rural households to sell or buy goods is reflected by "Market System", which is strongly depending on the existing road network and the available mode of transports. In fact, market access indirectly affects the economic situation of the communities. The market system can be assessed using the distance to the next market measured and the main mode of transport. "Forest-based knowledge" refers to traditional knowledge, practices and beliefs regarding the sustainable management of local forest resources as well as the knowledge about the functions of a forest ecosystem. In its widest sense it reflects the environmental awareness of the community. "Forest ecosystem stability" refers to the monetary or relative expression of the value of ecosystem services and natural resources associated with the use of forest by local communities. The parameter reflects both, the extraction of forest resources (e.g. fuel wood use) and the processing of forest resources (e.g. greenhouse gas emissions). However, the assessment of the forest ecosystem stability is relative to the total volume of forest services and resources and is considered as a measure of forest integrity at the current rate of forest services and resources uptake. "Infrastructure" refers to the basic physical structure needed for the functionality of a society and analyses the infrastructure development within the community. It was considered whether the communities had access to gas, electricity and whether water supply was guaranteed. Further, the access to a main road as well as mobile phone and internet connection were assessed.

The FCF concept has a flexible nature and can potentially be adjusted to measuring the overall levels of community poverty and forest productivity. Each parameter is calculated based on a set of weighed input variables, which can be adapted and changed to reflect the local conditions of the region of interest. Further, additional information can be used to complement the analysis and to provide an even more detailed assessment of the six FCF parameters (e.g. greenhouse gas emissions, gross domestic product). All variables are scored and a relative ranking is applied, where the upper and lower limits are defined by the the best and the poorest functioning community, respectively. Parameters are assessed on an ordinal scale ranging from 1 (very poor) to 5 (very good), meaning that an ideal community would score very well on every parameter, while an instable community would score very poor. An example of the hypothetical assessment of a community is provided in Figure 2.

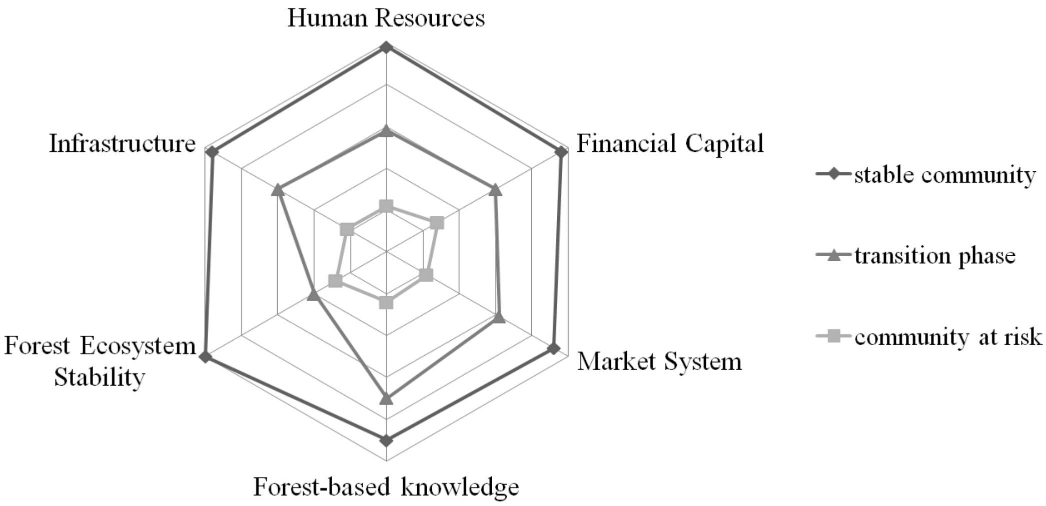


Figure 2: Forest Community Fingerprint – Hypothetical assessment of a well-functioning community (circle), a community in the transition position (triangle) and a poorly functioning community (square).

Extending knowledge derived from FCFs

Although the FCF-concept provides a sophisticated and detailed schematic of the interactions between the socio-economic and resource-based parameters of a rural community, it prevents its application to a large number of communities due to the need of extensive household data collection. For this reason, a statistical link between the ground-based survey data and the ecosystem profiles derived from Earth Observation (EO) information was developed that allowed the spatial expansion of the approach on a broader range of communities. By doing so, it was possible to derive calculated assumptions about rural communities that are not included in the field surveys, but are situated within the focus region. The approach to extend knowledge derived from the FCF to a set of unsurveyed rural communities required a series of subsequent analysis steps, which are shown in Figure 3 and outlined in more detail in the following section.

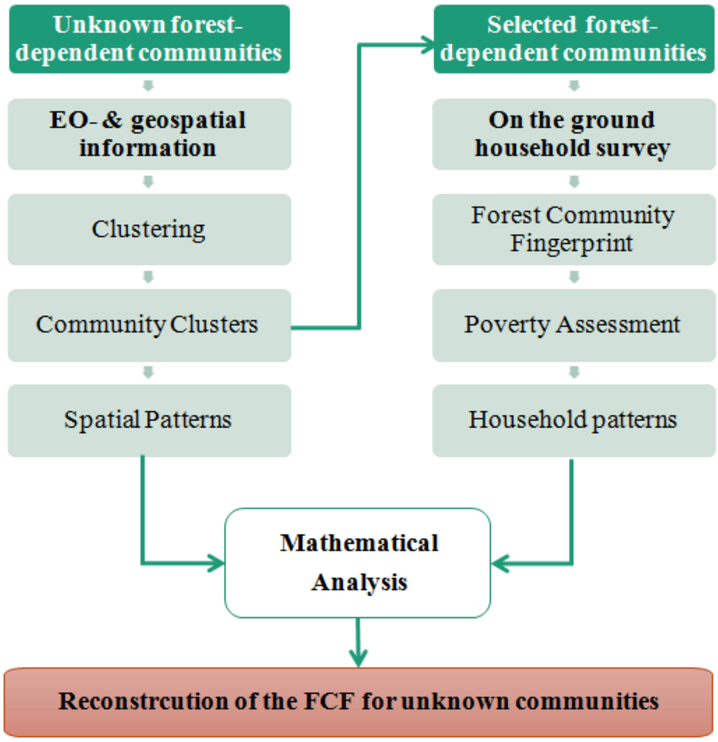


Figure 3: Steps needed to extent knowledge derived from the Forest Community Fingerprint to unsurveyed rural communities

Identifying forest-dependent communities across a broad landscape

In step one, all forest-dependent communities across a focus region are identified, counted, and geo-located using their latitude and longitude coordinates. The focus region may not be limited to a country and the number of communities is dependent on the local economic situation, population density, productivity and homogeneity of the landscape.

Establishing ecosystem profiles using EO-data

A ‘linking approach’ is used to establish an ecosystem profile for each of the rural communities that describes a community’s anthropogenic and natural environment. Hence, the ecosystem profile is defined by a function of six parameters which include 1) landscape characteristics, 2) village structure, 3) infrastructure, 4) agriculture, 5) forest and 6) hazard. "Landscape characteristics" refers to parameters that are describing the main physical features of the landscape and includes variables like extent and distribution of the main land cover classes, number of streams and rivers and land form. "Village structure" explains the geographic characteristics of a village as a settlement including the road structure, urbanisation and the house aggregation index. This parameter is supported by "Infrastructure", which refers to the fundamental structure needed for the functionality of a society and accounts for important infrastructure facilities (e.g. airports and railway stations) as well as for the remoteness of the community. "Agriculture" refers to the cultivation of plants, animals and other life forms for food, fibre, biofuel, medical and other products within the sample community. The main variables to describe this parameter are the approximate number, size and shape of agricultural fields within villages. Forest resources of a village are described by "Forest", which among others accounts for forest extent as well as forest gain and forest loss over the past few years. "Hazard" represents the exposure to or the possibility of loss, injury, or other adverse or unwelcome circumstances by the natural environment (e.g. flood and landslide risk).

To derive all ecosystem profiles from EO-based and other geospatial information in a standardized way, a 10x10km grid (100km²) with a grid size of 500m was generated around each village. The centre of this grid is the location of the community of interest as defined by the latitude and longitude coordinates. An example for Aknaghbyur (Armenia) is provided in Figure 4.

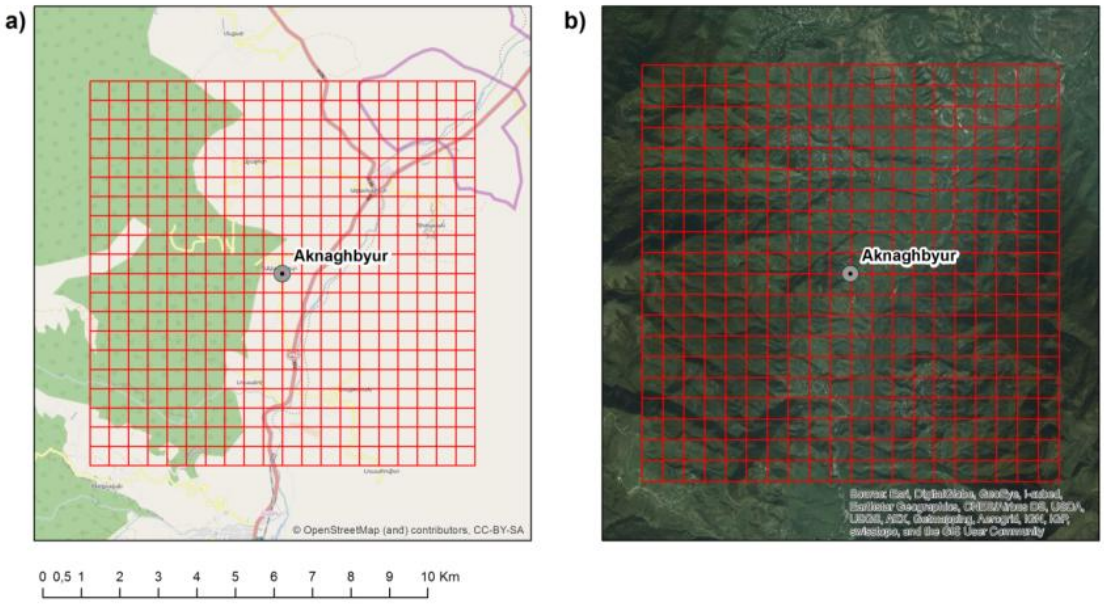


Figure 4: Example for the 10x10km grid used to analyse the geospatial and EO parameters with a) Open Street Map and b) Google Earth as a reference.

Grouping the ecosystem profiles according to similarities

Once all ecosystem profiles are established, fuzzy clustering analysis is applied to sort the forest-dependent communities common profile characteristics as derived from the EO-data. This analysis step may not always be necessary but in more heterogeneous landscapes it should be applied to sort communities by similarities. The number of clusters is dependent on the heterogeneity of the landscapes and communities themselves.

Selecting representative communities

From each of the clusters a representative subset of communities is chosen. Sample size depends on the total number of communities within a cluster, but the minimum number of samples per cluster should at least consist of three to ten samples and/or encompass a range between 10 to 25% of the total number, depending on the total absolute number of communities and desired confidence interval. This will guarantee an acceptable threshold of precision of the further analysis (e.g. 95% confidence level and ±5% confidence interval). The selected communities are subject to extensive field household surveys, as discussed in the following section.

Field household survey implementation

The household survey aims to examine the relationship between rural forest-dependent communities and their surrounding environment. The specific research questions include 1) What is the role of forests/environmental products in supporting current consumption in rural livelihoods of the surveyed communities?; 2) What is the relationship between human dependency on forests and household income/wealth levels?; 3) What are the common drivers that lead to increased human dependency on forests?; 4) How does the human dependency on forests change between regions and/or communities in their different stages of economic development (macroeconomic level) and contrasting access to markets (microeconomic level)?; and 5) How does human dependency on forests change between different (national or subnational) policy contexts?

The implementation of the field survey varies depending on the country, region, and landscape and the process follows a flexible and adaptive methodology. However, there are certain issues and criteria that should be considered in order to obtain an accurate representation of the community which include i) criteria for selection of surveyed communities itself, ii) incentives for engaging communities/ households in survey, iii) criteria for selection of key informants, iv) criteria for selection of focus group members, v) sampling strategy and selection of households as well as vi) data checking, coding and entering. Further, one in-depth qualitative interview with a key informant or village leader is recommended and is extremely useful to gather the village level data. An interview with a key informant or other knowledgeable person could help in collecting regional level data. After data compilation, a report is created following the PEN format structure (CIFOR-PEN 2007). This report gives structured qualitative information that can supplement the quantitative data collected. The report considers and/or incorporates many of the issues presented in Table 1. After successful implementation of the household survey, the results are compiled in a database where they can be utilized to develop the Forest Community Fingerprint.

Table 1: Overview of key issues that should be considered for the technical report of the household survey

Key issue	Parameters to be considered
Household survey procedure	Method of sampling (criteria used for selection of communities) Number of households (sample size) Timeline (start-end of each survey) Any additions/changes to survey, etc. Implementation, problems encountered etc. Local unit conversion (incl. from key informant interview)
Study area characteristics	Brief history of village Demographics (e.g. age composition, migration patterns, etc.) Infrastructure (e.g. connection to gas, electricity, water supply) Economic data (e.g. poverty levels, employment levels) Major economic activities (e.g., agricultural systems, timber trade, remittances) Seasonal calendar (e.g. major activities throughout the year (by month)) Major markets and market access (e.g. forest, agricultural, livestock, other) Major land cover and land uses and land use change Description of conservation areas: size, protection status, permitted uses, degree of enforcement. Tenure institutions: qualitative description of institutions governing the use of land, forests and natural resources Government and other development/conservation projects Any calamities (e.g., drought, fire, economic crisis, war, famine) Other relevant issues…
Descriptive statistics by grouping (e.g. region, or other characteristic)	Most common products – frequency and value Forest and environmental income over income quintiles Mean income shares

Establishing the Forest Community Fingerprint

Following the methodology described above, the Forest Community Fingerprint will be derived for the selected communities using the in situ data gathered during the household survey. Table 2 indicates the variables considered for each of the six parameters[1] selected as key dimensions for the fingerprint.

Table 2: Overview of potential parameters and variables to derive the Forest Community Fingerprint

Parameter	**Variable**
Human Resources	Years of education and highest degree Assessment of the household conditions Migration rate Age structure
Financial Capital	Income sources (e.g. Forest income, Non-Forest-Timber income, Income from agricultural activity, Income from animal products, Business income, Wage income, Other income (e.g. pensions)) Livestock assets Household assets
Market System	Distance to the next market measured in kilometers and in minutes Existence of black market and barter business
Forest-based Knowledge	Regulating service of forest ecosystems Provision service of forest ecosystems Cultural value of forest ecosystems Reason to plant trees
Forest Ecosystem Stability	Variables explaining the extraction of forest resources (e.g. fuel wood use) Variables explaining the processing of forest resources (e.g. Green house gas emissions)
Infrastructure	Access to main road Electricity supply Gas access Water supply Mobile phone and internet connection

The Forest Community Fingerprint results in the creation of a hexagonal spider web diagram, which is unique for each of the sample communities. The diagram demonstrates a

[1] Please note: These parameters can vary but for each country, region, or landscape they remain the same in order to establish relative comparability among the surveyed communities.

sophisticated view and a quantitatively-based assessment of the relationship between the community and its natural resource base. In addition to this, the diagram provides information on where and how to intervene and design mitigation strategies to foster and improve the resilience of the individual communities. To provide an example, Figure 5a) and b) show the variation between two rural communities. The spider web diagram in Figure 5a) reveals that as a first starting point any management intervention should incorporate a detailed analysis of the forest resource use patterns of the particular community. In contrast, Figure 5b) indicates a linkage between the market system, infrastructure and the forest ecosystem stability, which should be explored in more detail prior to implementing strategies.

a) b)

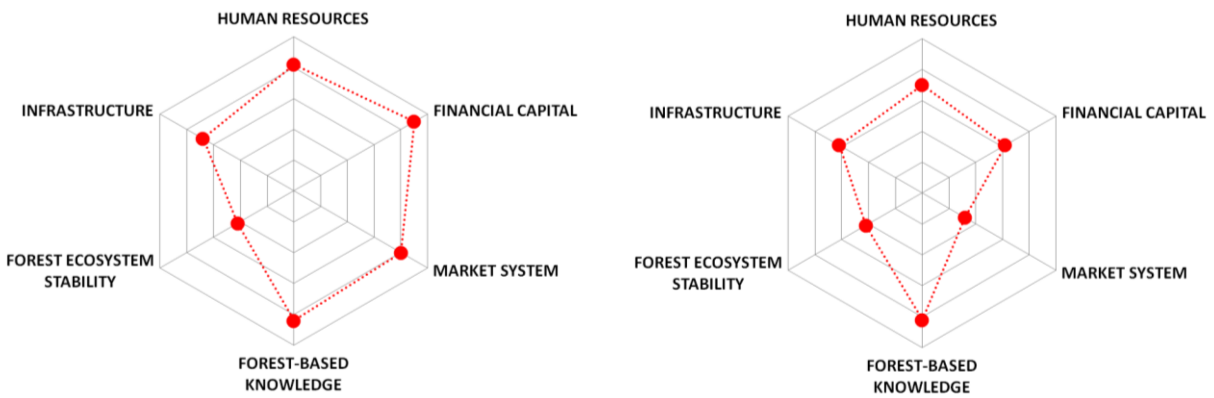


Figure 5: Example of the Forest Community Fingerprint Assessment for two different communities.

Poverty - Wealth Assessment

With respect to the utility of forest resources, the FCF may depend on the level of poverty in the respective community. Hence, a poverty-wealth assessment is implemented to differentiate between comparable spider web diagrams from different communities, which may be significantly different in terms of resilience and level of poverty and hence their susceptibility to climate change, forest fires and other disturbances. In order to account for the poverty level of a community, the net forest income is related to the total assets of a community. In general it is presumed that a community generating high forest income while having high assets is more resilient to risk situations than a community which has a very low forest income and is lacking the necessary assets to overcome a stress situation. Four categorical relationships are considered, which include 1) low assets - low forest income, 2) low assets - high forest income, 3) high assets - low forest income and 4) high assets - high forest income. The combination of the net forest income and the value of assets provides an insight into the relative potential risk of a community and are considered for interpreting and standardizing the results of the spider web diagramms.

Defining the EO parameters to describe the FCF

A General Linear Modelling (GLM) technique is proposed to estimate the leading descriptors of FCF parameters among the EO-data (see e.g. Christensen 2002). This method not only allows to simultaneously test the significance of multiple potential drivers within a single regression, but it also accounts for the interactions between the drivers. The choice of this technique is justified by its relative simplicity of algorithm and the robustness against data distribution irregularities. Further GLM has a proven versatility and reliability in comparison with the other model types and the possibility to mix categorical and continuous predictors within the same model (Elith und Leatherwick 2009). Quality check of results is routinely performed for each dependent variable (FCF parameter scores) with the help of residual analysis (comparison of observed versus predicted data values within a given model). The analysis enables detection of outliers in the data and ultimately their exclusion. GLM reveals both, i) the overall descriptive value of selected model (total R^2) and ii) the percentage of variance explained by each individual descriptor or their interactions. Hence, it pinpoints the most important predictors of the FCF parameters.

Reconstructing the FCF for unknown communities

Further extrapolation of knowledge on how EO and geospatial data defines FCF scores and shape to the unsurveyed communities are made using Principle Component Analysis (PCA) where each community carries a set of values for significant EO-data drivers derived from the GLM analysis. The FCF of an unsurveyed community is reconstructed using the maximum likelihood criterion (e.g. Bray-Curtis index, (Bray und Curtis 1957), Eucledian Distance, or visually on the graph) in respect to the "nearest" community where a field survey was performed. In case of intermediate position of an unsurveyed community between two or three communities where field surveys were performed, average weighed scores are calculated for the former one. For verification of the FCF reconstruction two methodologies can be applied. On the one hand, a stratified random subset of the reconstructed FCFs can be examined in the field utilizing the same household survey method used to establish the FCF and comparing both results. On the other hand, FCFs are reconstructed for a subset of surveyed communities based on an independent subset of the already surveyed communities. Reconstructed FCFs are compared with the actual ones received after surveys and several iterations are performed to assess statistical significance of the entire reconstruction. Although this method is less reliable, it provides assessment of significance with no additional resource input.

Application of the model: A case study from ENPI East FLEG II Countries and Russia

ENPI East FLEG II Framework

To estimate the true value of forest resources for rural communities in boreal forest ecosystems, the European Neighbourhood and Partnership Instrument East Countries Forest Law Enforcement and Governance II (ENPI East FLEG II) Program is analysing the dynamics between people and nature across Armenia, Azerbaijan, Belarus, Georgia, Moldova, Russia and Ukraine. The ENPI East FLEG II Program specifically addressed improved forest governance arrangements through the effective implementation of the main priorities set out in the St. Petersburg Ministerial Declaration and the Indicative Plan of Actions for the Europe and North Asia Forest Law Enforcement and Governance (ENA FLEG) process (World Bank 2005).

The main objectives of the ENPI East FLEG II Program were to develop a quantitatively-based framework to more accurately estimate the human dependency on nature in boreal and temperate forest ecosystems and to document the principal drivers of sustainable forest use as well as the various interactions between communities and available forest ecosystem resources. Further, the study assessed the true value of forest goods and ecosystem usage by these rural communities and provided quantifiable information to decision makers and stakeholders.

Study Area and data

Research was conducted in selected pilot regions across Armenia, Azerbaijan, Belarus, Georgia, Moldova, Russia and Ukraine. These countries were of particular research interest because hardly any study existed that provided a detailed analysis of the forest dependency of rural communities in northern temperate forest ecosystems. In total, 36 forest-dependent communities were chosen for this initial trial study and were subject to intensive household studies by the International Union for Conservation of Nature (IUCN). These villages were selected because they represented a variety of forest-dependent communities in the region ranging from very small and isolated villages to larger communities that have access to main roads and markets. Hence, the sample villages encompassed a high diversity of settings, which was critical for the intended analysis.

The aim of this pilot study was to develop a framework explaining the social-economic aspects of the human-nature dependency structure in northern temperate and boreal forest ecosystems. Further, it should help to estimate the value of forest goods and services for these rural communities. In the assessment of life quality and community income, the methodology followed the standards of the World Bank Living Standards Measurement Survey (LSMS 2014) and the Center for International Forestry Research (CIFOR) Poverty Environment Network (CIFOR-PEN 2007). The survey took place from March to August in 2013 and involved approximately 1250 households. Detailed information about the community forest dependency was gathered in two consecutive steps; i) on the village level by using focus group discussions as well as ii) on the household level using specific questionnaires. On the village level information on the household conditions, the market systems as well as the infrastructure were derived, while the household level questionnaire provided among others detailed information about the different income sources of a household's economy (e.g. forest income, business income) and the various assets held by the individuals and households (e.g. live stock assets). Further, variables explaining the extraction of forest resources (e.g. fuel wood use) and the processing of forest resources (e.g. Green house gas emissions) were collected. All sample communities are listed in Table 3 and their spatial distribution across the seven ENPI East FLEG II countries is provided in Figure 6.

Table 3: Sample communities across the ENPI East FELG II countries

Country	**Municipality/Region**	**Village**
Armenia	Lori Marz	Yegeghnut, Gargar
	Tavush Marz	Aknaghbyur, Hagharcin
	Syunik Marz	Halidzor & Tatev
Azerbaijan		Danachi, Yukhary Chardaglar, Yukhary Tala
Belarus	Buda-Koshelevo	Gubichi
	Gomel	Novaya Buda
	Milashevichi	Ivanova Sloboda
	Rudnya-Viktorinskaya	Rudnya-Viktorinskaya
Georgia	Tianeti	Sakdrioni, Artani, Zhebota, Chabano, Zaridzeebi
Moldova	Central, Nisporeni district	Cioresti
	South, Cahul district	Borceag
	North, Soroca district	Alexandru cel Bun
Russia	North West of European Russia	Tsevlo, Bezhanitsy, Krasny Luch
	Altai	Yeltsovka, Volchno-Burlinskoe, Tyumentsevo
	Russian Far East	Mukhen, Sita, Sikachi-Alan
Ukraine	Lviv / Yavoriv	Seredkevychi, Smolyn
	Velykobereznianskyi	Zahorb, Strychava
	Bereznivskyi	Kolodyazne, Bystrychi

Figure 6: Spatial distribution of the 36 sample communities across the ENPI East FELG II countries

Derivation of the EO-based ecosystem profiles

The EO-based ecosystem profiles were established for all 36 forest-dependent communities and stored in a spatial database. Following the examination of a variety of indices for determining the optimal number of clusters a partitioning around medoids (PAM) cluster analysis was applied to group the rural communities according to their similarities in the EO-data. In total, three clusters were determined by the PAM analysis (see Table 4).

Table 4: Differentiation of the 36 communities into three clusters.

	Communities
Cluster 1	Aknaghbyur, Artani, Chabano, Gargar, Haghartsin, Halidzor, Meliaskhevi, Sakdrioni, Tatev, Yeghegnut, Yukhari Chardakhlar, Yukhari Tala, Zahorb, Zaridzeebi, Zhebota
Cluster 2	Alexandru cel Bun, Bezhanitsy, Borceag, Cioresti, Krasnyi Luch, Mukhen, Novaya Buda, Seredkevichy, Sikachi Alan, Sita, Smolyn, Tsevlo, Tyumentsevo, Volchno Burlinskoe, Volovita, Yeltsovka,
Cluster 3	Bystrychi, Danachi, Gubichi, Ivanova Sloboda, Kolodiazne, Rudnya-Viktorinskaya

Fingerprinting 36 forest-dependent sample communities

The FCF was derived for the 36 forest-dependent communities. The main statistics for each parameter of the Forest Community Fingerprint are summarized in the Table 5.

Table 5: Main statistics for each FCF parameter to rank the communities

FCF Parameter	Mean	Std. Dev.	Lower threshold (mean - Std. Dev.)	Upper threshold (mean + Std. Dev.)
Human Resources	3.45	0.16	3.28	3.61
Financial Capital	2.67	0.60	2.07	3.28
Market System	2.91	0.79	2.12	3.70
Forest-based Knowledge	3.60	0.60	3.00	4.21
Forest Ecosystem Stability	2.18	0.52	1.66	2.70
Infrastructure	3.11	0.85	2.26	3.96
Average FCF	2.99	0.26	2.74	3.25

Based on the statistical parameters listed in Table 5 as well as the relative poverty assessment the 36 communities were ranked according to their average FCF (Table 6). In total, seven communities were at risk (lower threshold) and 5 communities were stable (upper threshold). The majority of communities (24) were considered as in the transition phase, with 11 communities being rather at risk and 13 rather stable, respectively. However, for these 'transition' communities it is not possible to determine whether they are transitioning towards a more stable or a less stable situation, respectively.

Table 6: Relative ranking of the 36 forest-dependent communities based on the FCF

<table>
<tr><th colspan="2">Functionality</th><th>Name of community</th></tr>
<tr><td colspan="2">Community at risk</td><td>Artani, Smolyn, Tsevlo, Rudnya-Viktorinskaya, Danachi, Zahorb, Ivanova Sloboda</td></tr>
<tr><td rowspan="2">Community in transition phase</td><td>Rather instable</td><td>Borceag, Bystrychi, Gubichi, Halidzor, Kolodyazne, Novaya Buda, Seredkevychi, Sikachi-Alan, Strychava, Yukhari Chardakhlar, Zhebota</td></tr>
<tr><td>Rather stable</td><td>Alexandru cel Bun, Aknaghbyur, Chabano, Gargyar, Haghartsin, Krasny Luch, Mukhen, Sita, Tatev, Volchno-Burlinskoe, Yeghegnut, Yeltsovka, Zaridzeebi</td></tr>
<tr><td colspan="2">Stable community</td><td>Bezhanitsy, Cioresti, Sakdrioni, Tyumentsevo, Yukhari Tala</td></tr>
</table>

As an example of community risk analysis in Figure 7 we present the spider web diagrams for five communities to illustrate the different and complex interactions of the parameters for these five selected communities. Tsevlo village demonstrated the highest score for human resources and the financial capital compared to the other communities. Other parameters in the FCF for this village are relatively low. According to our findings, Tsevlo demonstrated the lowest level of forest-based knowledge and infrastructure development. The forest ecosystem stability is rather low as well. This combination may indicate that forest resources might not be effectively and sustainably managed and provides a good starting point for any potential intervention. Another explanation for this may be the existing past environmental damage in the area from the peat extraction stopped three decades ago but still has not been mitigated. Smolyn village has a well educated community and relatively high levels of human resources and forest-based knowledge. The market system and infrastructure in this village are also well developed. However, the financial capital in Smolyn is very low. Forest ecosystem stability here is one of the lowest in our sample. Cioresti community is relatively stable compared to the others and the village shows high levels for human resources and financial capital as well as market system and infrastructure. Forest ecosystem stability in Cioresti however, is among the lowest across the sample. Indeed, decisions regarding improving livelihood in this village should target improving forest sustainability. Sakdrioni is the most stable community among the ones reviewed. Results indicate that all FCF parameters have values which are above average levels. Human resources and infrastructure have the highest scores among all villages in the sample. This community also demonstrates the highest score for forest ecosystem stability, which is in concordance with the FAO forest resources statistics indicating a recent increase in forest extent for Georgia (FAO 2010). Finally, compared to the other communities, Ivanova Sloboda is the most unstable one. Our results show very low values for financial capital, market systems and infrastructure development. Interestingly, forest ecosystem stability is rather high and comparable to that for

Sakdrioni. This is most likely the consequence of a well educated community with a well developed forest-based knowledge.

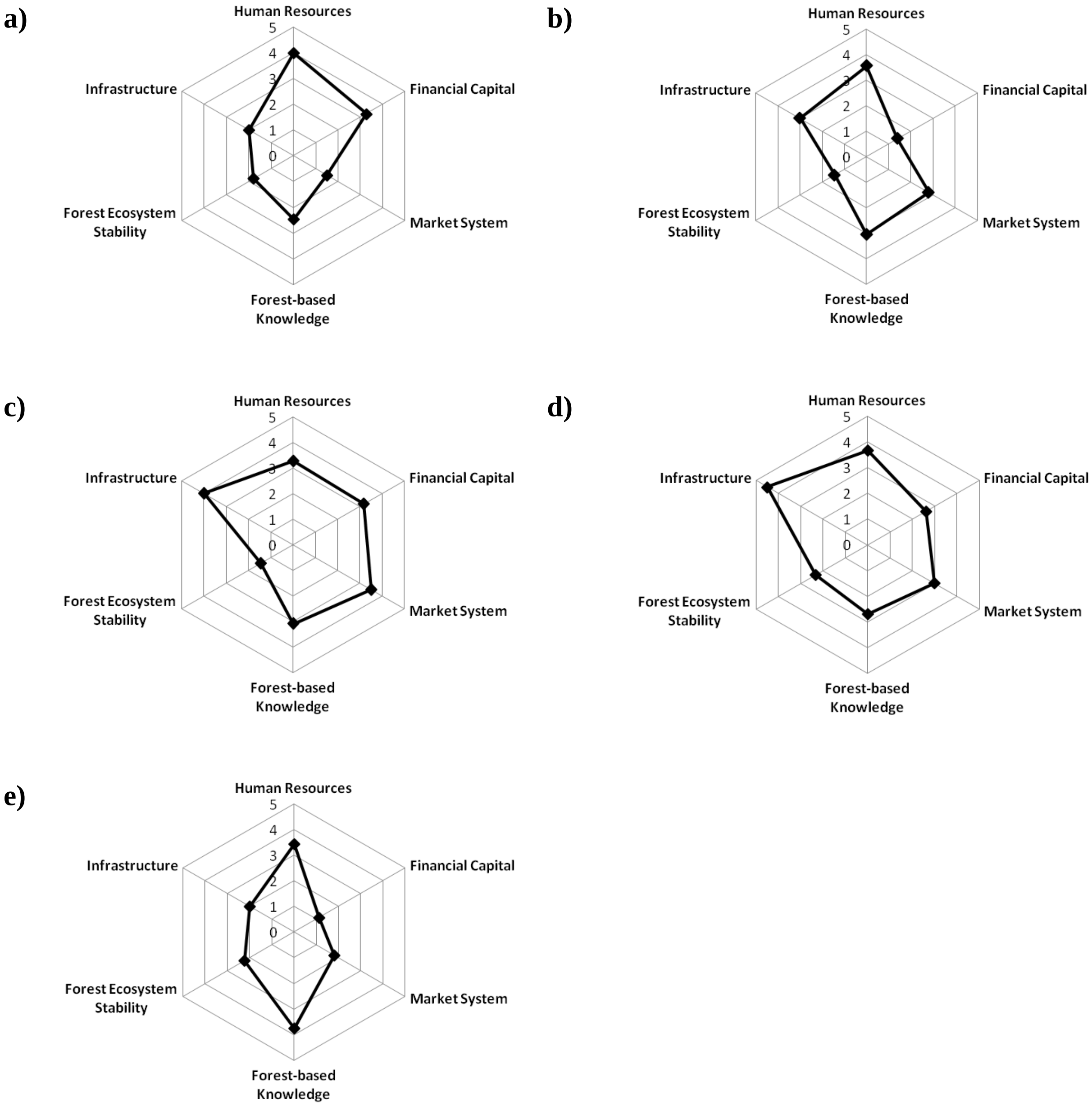


Figure 7: Forest Community Fingerprint for a) Tsevlo, b) Smolyn c) Cioresti d) Sakdrioni and e) Ivanova Sloboda. Please note: Values range from 1 (very poor) to 5 (very good).

Testing extrapolation methodology

As only a single community field survey was performed within this case study area, we were able to complete only preliminary steps towards extrapolating knowledge on FCF to the unsurveyed communities. For the same reason we also were forced to use second type of verification for the elaborated extrapolation model (see section “Reconstructing the FCF for unknown communities" above for explanations). The standard GLM was applied using the factor groups "Land cover distribution", "Slope", "Elevation class", "Road structure", "Urbanization", "Remoteness from the markets", "Forest extent", "Land slide risk" and "Flood risk" as categorical predictors (Table 8 in the Appendix). Only main effects of the factors were left in the model after some preliminary testing. For each of the selected FCF parameters, the GLM described over 72% of the total dependent data variance at a high significance level ($p<0.0055$). GLM analysis showed that the "Human resources" parameter was not sufficiently described by any of the factors included into the model. "Forest extent" group of factors explained over 60% of the variance of "Financial Capital" within the entire dataset, "Market System" dimension of FCF was mainly determined by "Land cover" group of factors (over 60% of the total variance explained) and, as expected to some extent, by "Road structure" and "Tree cover". "Forest-based knowledge" was mainly dependent on "Land cover" with over 40% of the total variance explained. "Elevation range", "Secondary roads" and "Forest extent" additionally contributed with 5-10% to the variance explanation of this FCF parameter (see Table 8 in the Appendix). "Forest Ecosystem Stability" was dependent on the variables "Slope (low hills)" and "Forest extent" group of factors, in total explaining about 35% of the parameter variance. "Land cover" group of factors described another 35% of variance of "Forest Ecosystem Stability". Finally, "Infrastructure development" was strongly driven by "Land cover". The total percentage of managed, urban lands and water had the strongest influence on "Infrastructure development" (jointly over 50% of the total variance explained.

Based on the results of the GLM analysis, and to further simplify the process of FCF reconstruction for unsurveyed villages, a Principal Component Analysis (PCA) was performed. PCA helped to define the direction and confirm the overall strength of the relationship between significant drivers among the EO-data for each of six respective FCF parameters. FCF parameters were included as active variables into PCA, while EO-data were incorporated as passive ones. In total, the two first axes of PCA accounted for approximately 48% of the total variance in the data. The results of the PCA are provided in Figure 8 and the most important drivers of FCF parameters are shown in Table 7.

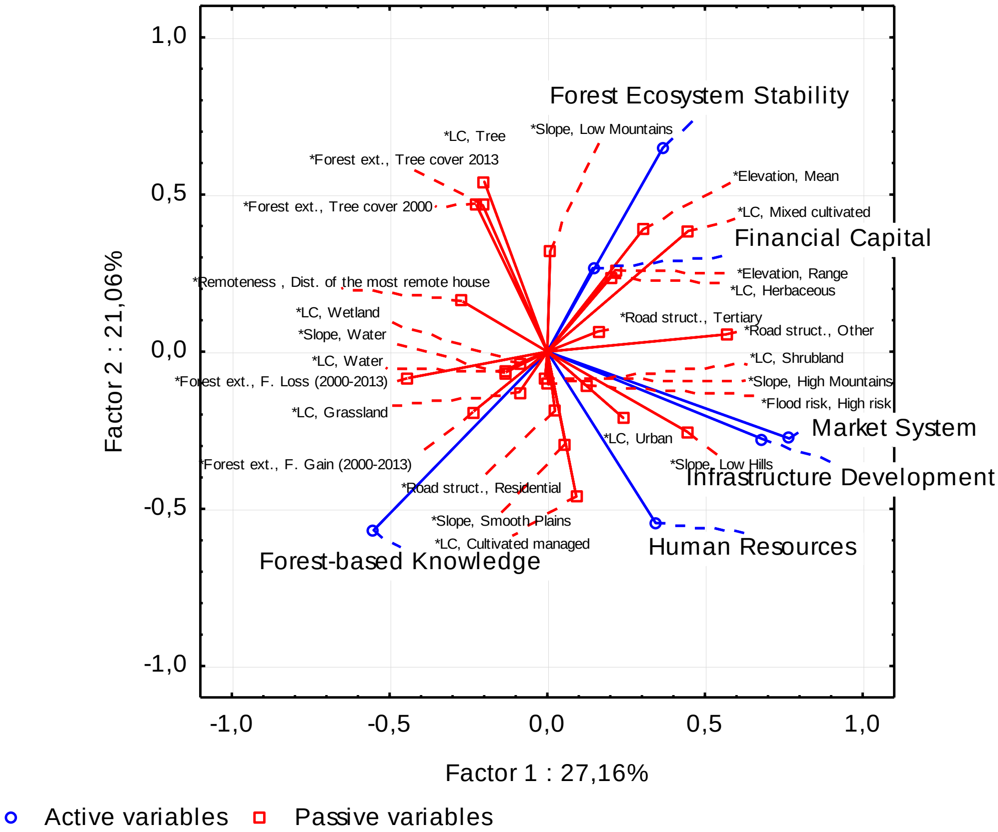


Figure 8: Results of PCA with FCF parameters introduced as active and EO-data as passive variables (marked with asterisk on the graph). Abbreviations: LC – Land cover.

Table 7: Most important factors correlating positively or negatively with the six FCF parameters

FCF parameter	**Positive correlation**	**Negative correlation**
Financial Capital	Elevation Mean Land cover, mixed cultivated land	Forest Extent, Forest Gain (2000-2013)
Forest Ecosystem Stability	Elevation, Mean Land cover, mixed cultivated land	Forest Extent, Forest Gain (2000-2013)
Forest-based Knowledge	Forest Extent, Forest Gain (2000-2013)	
Market System	Land Cover, Urban Slope, Low Hills	Remoteness, Distance of the most remote house from a main street
Infrastructure Development	Land Cover, Urban Slope, Low Hills	Remoteness, Distance of the most remote house from a main street
Human Resources	Land Cover, Cultivated land Land Cover, Urban Territories	Forest extent, Tree Cover 2000 and 2013 Land Cover, Trees

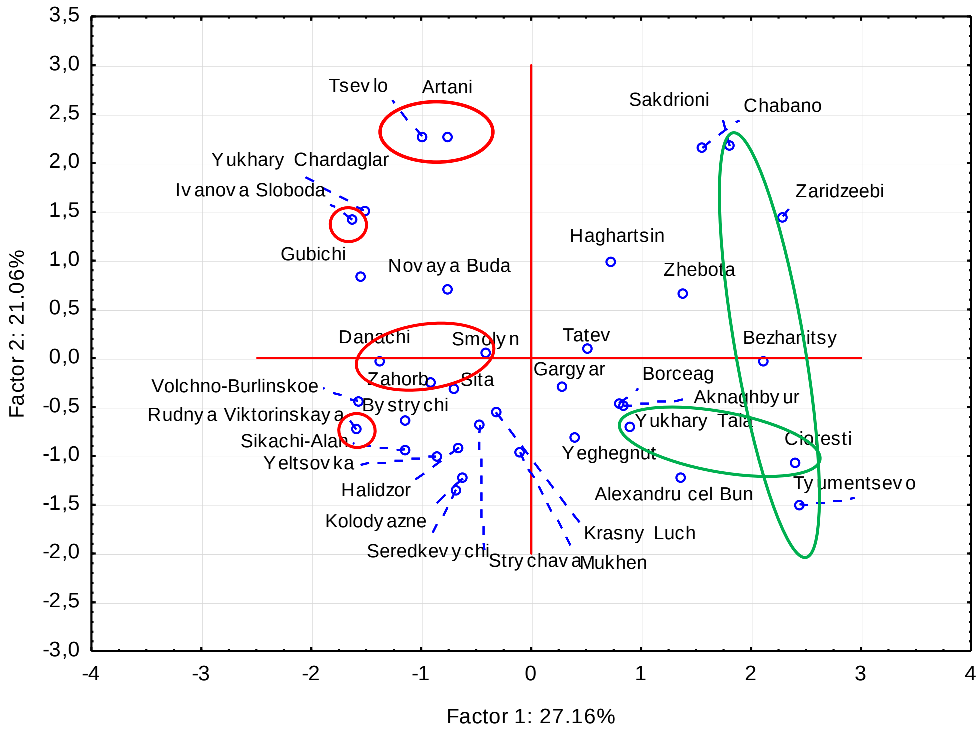
Figure 8 and Table 7 show that Financial Capital parameter in the surveyed forest-dependent communities strictly and positively corresponds to the Forest Ecosystem Stability. At the same time both of these parameters are counter-correlated with the Forest-based Knowledge. Market System and Infrastructure Development are orthogonal to the former three variables and are hence, independent from them. Market System and Infrastructure Development are strongly positively related to each other. Human Resources have an intermediate position and are equally independent from Market System and Infrastructure development as well as Forest-based Knowledge.

Among EO-data, Forest Ecosystem Stability and Financial Capital have a strong positive relation to mean elevation and to a smaller extent with the area of mixed cultivated land. At the same time, it is negatively correlated with the Forest Gain in 2000-2013. Higher Forest Gain corresponds with the increase of Forest-based Knowledge. Human Resources are positively related with the percentage of Land Cover parameters: Cultivated Land and Urbanization. At the same time, there is a strong negative relationship between this FCF parameter and Forest Cover and Tree Cover factors. Market System and infrastructure development are positively driven by the value of Slope, Low Hills factor, and negatively related with Remoteness of the most remote house from the main village street.

Joint results of the GLM and the PCA clearly show that there is a limited set of EO-data drivers (Table 7), which is a positive indication in the attempt to reconstruct FCF in any of the unsurveyed villages within a focus region. Another aspect of the forest-dependent community field survey data extrapolation to the unsurveyed villages is related with comparison of PCA scatterplots for the individual communities built using FCF parameters and EO-data separately, which is provided in Figure 9. The separation of at-risk and stable communities as defined in Table 6 within the set of 36 villages is traceable in both scatterplots (Figure 9 A and B) but is less pronounced for the scatterplot based on EO-data (Figure 9 B).

This is explained by the impact of regional differences and once more appeals to the necessity of the poverty assessment and post-analysis field data verification and model adjustment. However, visible community separation according to their risk rank within our dataset allows further risk assessments for unsurveyed communities within the same region, which is exclusively based on the EO-data.

a)



b)

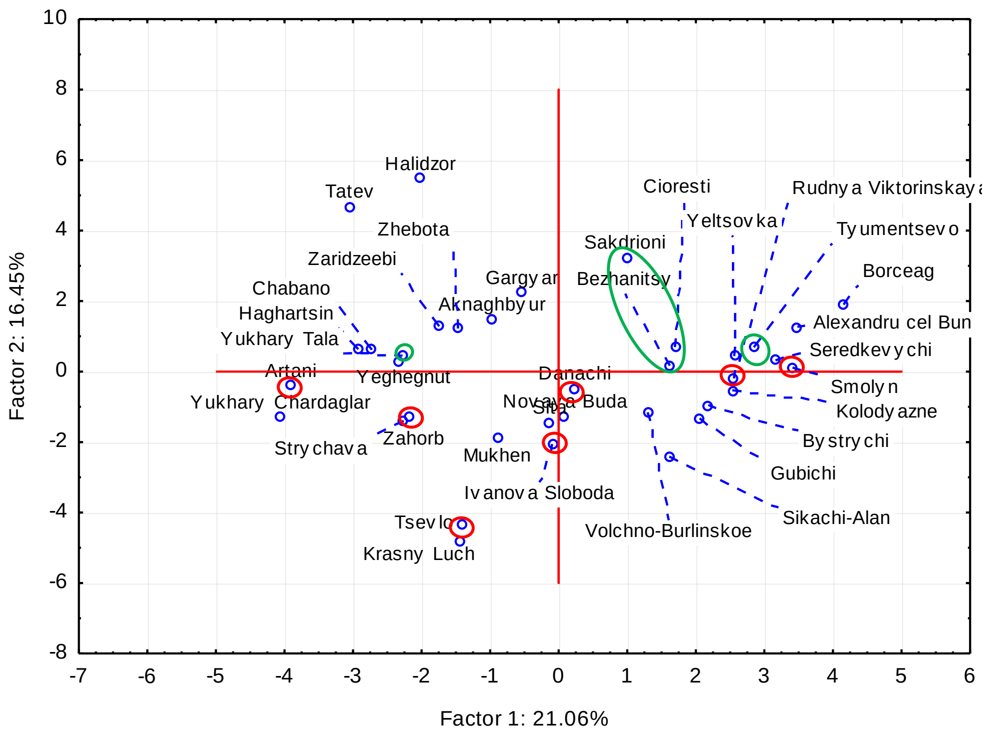


Figure 9: Results of PCA for 36 surveyed communities is built based on: a) six FCF parameters; b) significant EO-data drivers (z-transformed) as defined in Table 8 in the Appendix. Red and green ovals mark communities at risk or in stability respectively (See Table 6).

Discussion and Conclusions

Forest-dependent rural communities require policies and management strategies that foster the sustainable use of forest resources in order to improve livelihood benefits. However, to target management decisions it is essential to understand interactions of factors that lead to i) forest degradation and loss as well as ii) forest gain and sustainable forest usage. The presented conceptual framework provided a statistically justified methodology for assessment of community stability and resilience at vast territories. It is based on the comparative analysis which engages data derived from comprehensive household surveys (Forest Community Fingerprint) as well as Earth Observation and other geospatial data (ecosystem profiles).

This methodology was successfully tested across the northern temperate and boreal forest ecosystems and may be applied in the future for the wider range of ecoregions and territories. The Forest Community Fingerprint provides a sound representation about the human-nature dependency in the 36 sample communities and clearly identifies weaknesses or insertion points in the community development. Our results for the five case communities, Tsevlo (Russia), Smolyn (Ukraine), Cioresti (Moldova), Sakridioni (Georgia) and Ivanova Sloboda (Belarus) align with observations in the field and indicate the feasibility of the Forest Community Fingerprint concept. By including the poverty-wealth assessment, we may also reflect the local socio-economic situation and place our analysis into the poverty context.

Of course, our concept is a broad approach that is not able to fully account for local conditions, e.g. our assessment of the market system does not include illegal markets or barter business, which is essential for the livelihoods in some communities. Further field survey and quality check of a subset of earlier unsurveyed communities may increase the quality of such a risk assessment. Nevertheless, we are confident that by using the proposed highly adaptive methodology, we are able to identify communities at risk and to give a robust insight into the complex relationship between socio-economic aspects and the facets of forest use, which is essential for the policy and management decision process. Already at the current stage of methodology development, the FCF can be used as a tool to help stakeholders and policy makers in taking immediate measures to improve livelihood and to promote local poverty alleviation strategies. Our next steps will be to perform the same assessment on a larger sample of forest- dependent rural communities and to reconstruct the FCF for communities prior to the field studies. Further, we will test to which extent it is possible to apply the proposed methodology in other forest ecosystems such as the tropical rainforest.

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Appendix

Table 8: Results of GLM analysis of factors explaining variance in the FCF scoring among surveyed communities. Factors describing more than 5% of the total parameter variability are marked in bold.

	Human resources		Financial Capital		Market System		Forest-based knowledge		Forest Ecosystem Stability		Infrastructure development	
Model Multiple R^2	0.7488		0.7642		0.9578		0.7394		0.8246		0.8708	
Model p-level	<0.0051		<0.0001		<0.0001		<0.0003		<0.0002		<0.0004	
Factors	% variance explained	p-level	% variance explained	p-level	% variance explained	p-level	% variance explained	p-level	% variance explained	p-level	% variance explained	p-level
INTERCEPT	**98.89**	<0.0001	**6.25**	0.0006	**6.82**	<0.0001	17.62	<0.0001	4.21	0.0149	6.30	0.0066
COUNTRY - GROUPING FACTOR												
Land cover distribution. Barren												
Land cover distribution. Cultivated managed			**5.71**	0.0009	**6.81**	<0.0001	**8.20**	0.0004	4.23	0.0147	**8.39**	0.0024
Land cover distribution. Grassland			2.98	0.0119	**6.81**	<0.0001	4.93	0.0043	4.22	0.0148		
Land cover distribution. Herbaceous					**6.82**	<0.0001			4.28	0.0142		
Land cover distribution. Mixed cultivated			4.38	0.0030	**6.84**	<0.0001	**10.50**	0.0001	4.26	0.0145		
Land cover distribution. Shrubland					**6.83**	<0.0001	3.35	0.0154	4.22	0.0148		
Land cover distribution. Tree					**6.84**	<0.0001	3.74	0.0110	4.22	0.0148		
Land cover distribution. Urban					**6.88**	<0.0001			4.20	0.0151	**21.18**	<0.0001
Land cover distribution. Water					**6.80**	<0.0001	**7.13**	0.0009	4.23	0.0147	4.57	0.0174
Land cover distribution. Wetland					**6.85**	<0.0001			4.31	0.0140	**18.24**	<0.0001
Elevation. Mean											3.69	0.0299
Elevation. Range	0.31	0.0025			3.03	0.0003	**5.49**	0.0028				
Slope. Breaks/Foothills												
Slope. Flat plains												
Slope. High Mountains	0.14	0.031076										
Slope. Hills												
Slope. Low Hills			1.88	0.0410					**12.76**	0.0002		
Slope. Low Mountains					1.30	0.0081						
Slope. Smooth Plains					2.17	0.0014						
Slope. Undefined												
Slope. Water											4.57	0.0174
Road structure. Motorway												
Road structure. Primary												
Road structure. Secondary							**9.51**	0.0002	**5.00**	0.0088		
Road structure. Tertiary					1.48	0.0054	4.26	0.0072			3.41	0.0359
Road structure. Residential					0.79	0.0307						
Road structure. Other					**8.42**	<0.0001						
Urbanization. Houses aggregation index												
Remoteness. Most remote house			4.57	0.0025			4.60	0.0055			4.46	0.0185
Forest extent. Forest Gain (2000-2013)							2.81	0.0251	**7.22**	0.0023	3.42	0.0358
Forest extent. Forest Loss (2000-2013)	0.18	0.0166	**24.71**	<0.0001	1.27	0.0088			**11.35**	0.0003		
Forest extent. Tree cover 2000			**18.17**	<0.0001	4.58	<0.0001			4.92	0.0093		
Forest extent. Tree cover 2013			**17.99**	<0.0001	**5.09**	<0.0001	**6.61**	0.0013	4.47	0.0125		
Landslide risk. High risk (4)												
Landslide risk. Very high risk (5)												
Flood risk. Very high risk (5)												

Flood risk. High risk (4)			2.76	0.0151	1.65	0.0037					3.61	0.0315
ERROR	0.49		10.59		1.92		11.25		11.88		10.40	