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Why do forest products become less available? A pan-tropical comparison of drivers of forest-resource degradation

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Abstract

Forest products provide an important source of income and wellbeing for rural smallholder communities across the tropics. Although tropical forest products frequently become over-exploited, only few studies explicitly address the dynamics of degradation in response to socio-economic drivers. Our study addresses this gap by analyzing the factors driving changes in tropical forest products in the perception of rural smallholder communities. Using the poverty and environment network global dataset, we studied recently perceived trends of forest product availability considering firewood, charcoal, timber, food, medicine, forage and other forest products. We looked at a pan-tropical sample of 233 villages with forest access. Our results show that 90% of the villages experienced declining availability of forest resources over the last five years according to the informants. Timber and fuelwood together with forest foods were featured as the most strongly affected, though with marked differences across continents. In contrast, availability of at least one main forest product was perceived to increase in only 39% of the villages. Furthermore, the growing local use of forest resources is seen as the main culprit for the decline. In villages with both growing forest resource use and immigration—vividly illustrating demographic pressures—the strongest forest resources degradation was observed. Conversely, villages with little or no population growth and a decreased use of forest resources were most likely to see significant forest-resource increases. Further, villages are less likely to perceive resource declines when local communities own a significant share of forest area. Our results thus suggest that perceived resource declines have only exceptionally triggered adaptations in local resource-use and management patterns that would effectively deal with scarcity. Hence, at the margin this supports neo-Malthusian over neo-Boserupian explanations of local resource-use dynamics.

1. Introduction

Forest products provide an important income source for smallholder rural communities in the tropics, and they contribute significantly to their wellbeing (Byron and Arnold 1999, Reyes-García *et al* 2015). Large-scale comparisons and meta-studies revealed that approximately one quarter of total household income of rural

communities in developing countries stems from forests—with forest-based income shares being tentatively higher for low-income households with good forest access (Vedeld *et al* 2007, Angelsen *et al* 2014). However, forest products often locally become over-exploited, especially when a combination of open-access regimes and growing demand for primary forest products from local population prevail (Palm *et al* 2005, Carr 2009).

Several recent studies which explored drivers of forest cover change in the tropics concluded that agriculture and the demand for new cultivated lands is the main cause of tropical deforestation (Rudel *et al* 2009, DeFries *et al* 2010, Hosonuma *et al* 2012). Yet, studies exploring the effects of deforestation and forest degradation on the availability of forest products are scarce, and limited to localized case studies (e.g. Appiah *et al* 2009). Additionally, inter-temporal studies on the drivers of forest product changes in response to various drivers are missing. Besides, little information on the socio-economic context affecting the availability of tropical forest products has been gathered. Our study addresses this gap by identifying demographic, institutional and management-related factors that govern changes in availability of forest products over time in smallholder rural forest communities in the tropics and subtropics. We used a pan-tropical household-based dataset of perceived changes in forest product availability to explore which drivers of change could be identified, determining their relative importance. Specifically, we provide new, global-comparative insights into the relative importance of demographic, institutional and management-related drivers of forest resource dynamics.

2. Trends of tropical forest resources and local evidence

Anthropogenic forests are complex socio-ecological systems with various feedbacks in time and space. Multiple forest use typically involves numerous direct and indirect drivers affecting the availability and accessibility of forest resources. As these resources form a crucial and direct contribution to the livelihood of local inhabitants—especially the poor—degrading the resource base potentially increases livelihood vulnerability (Sunderlin *et al* 2005). Several localized case studies have illustrated the importance of incomes from forest products, which sometimes almost equals the agricultural income (Fisher 2004, Mamo *et al* 2007, Appiah *et al* 2009). Growing populations may also increase pressures on forests through deforestation and forest degradation (Geist and Lambin 2002, Carr 2009, DeFries *et al* 2010, López-Carr and Burgdorfer 2013). While such neo-Malthusian narratives are amply supported by evidence at multiple scales (e.g. Seppelt *et al* 2014), neo-Boserupian scholars conversely suggest that an increasing population could trigger societal incentives for transitioning into intensified, sustainable resource uses (Ostrom and Nagendra 2006). Yet, in the context of forest dynamics attention to neo-Boserupian alternatives has been restricted due to the dominant presumption of prevailing Malthusian relationships (as criticized by Leach and Fairhead 2000).

Relatively little is known on the effects of forest resource degradation on forest product availability

beyond timber. Appiah *et al* (2009) illustrate for Ghana that the decline of forest products used by the local people is largely a result of poverty-driven agricultural expansion into forests. But in the same country, large-scale land transfers (often referred to as ‘land grabbing’) have also restricted local people’s access to forest products and reduced their welfare (Schoneveld *et al* 2011). In Zambia, however, large-scale biofuel plantations expanding into forestlands have not caused a decline in forest product availability, because enough forest was left to fulfill local people’s needs (German *et al* 2011).

Nevertheless, local governance systems such as community-based resource management, might effectively withstand forest resource degradation by enabling local people to use their knowledge to manage natural resources sustainably (Armitage 2005, Dressler *et al* 2010). Case studies indicate that local resource users can potentially enforce access regulations to the commons (such as forests) (Pomeroy 1995, Johannes 2002, Armitage 2005)—opposed to the classical ‘tragedy of the commons’ scenario where open access leads to inevitable resource degradation (Hardin 1968). This debate features divergent paths of common resource use, demographic transition and the distinction between common property and open access resources.

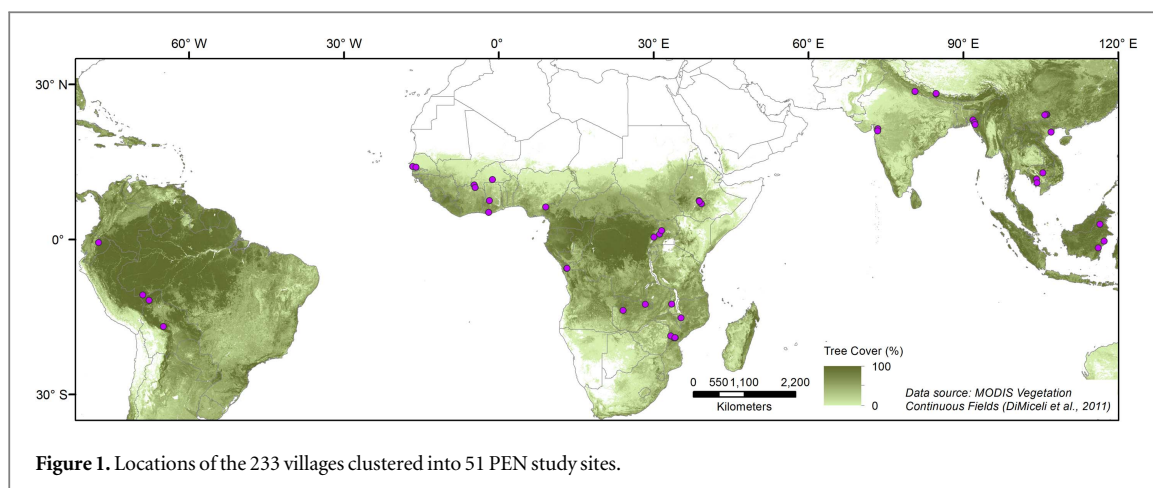
3. Data and methodology

3.1. The poverty and environment network (PEN) survey

Our analysis draws on the PEN database, which was compiled by the Center for International Forestry Research (CIFOR)⁸. The PEN data is a pan-tropical, standardized dataset of household incomes, assets, and livelihood systems. It allows for some global-comparative quantitative analyzes that go beyond case studies in terms of generalizable conclusions regarding factors affecting tropical forest resource base. The PEN data comprise social, ecological and economic information obtained from standardized interviews for 8301 households in 334 villages across 59 study sites in 24 tropical countries in Sub-Saharan Africa, Latin America and Asia. The data can be considered as a representative sample of smallholder-dominated tropical and sub-tropical landscapes with households having access to forest resources (Wunder *et al* 2014).

Our study draws on village surveys implemented between January 2005 and May 2010, providing information on villagers’ perceptions of changing availabilities of main forest resources over the last five years, and the perceived causes of this change. In addition, the village focus groups provide information on land management, demographics (including

⁸ For additional information on the PEN database see www.cifor.cgiar.org/pen.



migration) and other potential drivers of change. From the initial 334 villages, we restricted our analysis to those 233 villages for which the needed complete survey data existed (figure 1).

3.2. Availability of forest products

The PEN data provides information on six forest resource types: firewood and charcoal, timber and other wood, food, medicine, forage, and others. Respondents ranked their relative importance, and stated what they perceived as their change in availability (stable, increase, or decline) over the last five years prior to the survey. Across the 233 villages the three most important forest products for local livelihood were firewood and charcoal, timber and other wood, and food. In two thirds of the villages, local people used all those three forest product types. Medicine and forage were less important for the village wellbeing, though 75% of the villages used one or other of these resources.

We then aggregated the changes in availability of the individual forest products across the six categories per trend (perceived increase and perceived decrease) to get a more general perception. Our aggregated indicator for perceived forest product decline was calculated as the percentage of the number of declining forest products from the total number of available products in each village as reported by the informants. Analogously, the percentage of perceived forest product increase was calculated as the percentage of the number of increasing forest products from the total number of available products in each village according to the informants.

The PEN household surveys provide reasons for changes of the individual forest product availability as perceived by the village population, specified for both increasing and decreasing availability. Those reasons were pre-structured, with binary responses (Does this suggested reason for change apply? Y/N). We then aggregated these reasons across the six resource types, indicating to what extent a particular reason, for example *increased forest product use* applied to the

respective village or not. In this way, we identified the relevance of each reason for both perceived increase and perceived decrease of forest resources per village (see table 1; independent variables: self-reported reasons for forest product decline/increase). Finally, we juxtaposed the aggregated information on forest product availability to village-level context conditions: forest type, area, management regime, use regulations, demographics (see table 1; independent variables: framing conditions) in statistical analyzes. Appendices A and B show frequency distributions and correlations between the variables used, respectively.

3.3. Analysis

We applied a random forest regression tree procedure to explore the drivers of both the perceived decline and perceived increase of forest products. Regression trees allow for revealing unknown nonlinear, multivariate patterns with high-order interactions, which typically occur in socio-ecological systems (De'ath 2002, Archibald *et al* 2009, DeFries *et al* 2010, Bonilla-Moheno *et al* 2012). Regression trees explain variation of a single dependent variable by recurrently splitting the data into more homogeneous subsets, referred to as 'nodes', by using combinations of categorical and/or numerical independent variables without making assumptions on the statistical distribution of the data (Breiman 2001). Each node is characterized by a typical value of the dependent variable, the number of observations in the node, and the values of the independent variables defining it. Random forest procedures apply bootstrapping to grow a large number of regression trees—hence, a forest of trees—to both improve the predictive power of regression tree models and reduce overfitting (Breiman 2001, Prasad *et al* 2006).

For the random forest analyzes, we used each percentage perceived forest product decline/increase as dependent variable. 500 trees were grown based on a randomized subset of independent variables using five independent variables at each split. All trees were grown without pruning, and the final result is the

Table 1. List of variables included in the analysis. All variables were derived from the PEN village survey.

Variable	Definition	Range [Min, Max]	Mean (Std. dev.)
Dependent variables			
Forest product decline	Percentage of locally most important forest products for which availability has decreased over the past five years according to the informants	[0, 100]	66 (34)
Forest product increase	Percentage of locally most important forest products for which availability has increased over the past five years according to the informants	[0, 100]	16 (26)
Independent variables: framing conditions			
State forest	Forest area (natural forests, managed forests and plantations) formally owned by the state at national or regional level (some rules enforced), as percentage of total forest area	[0, 100]	26 (41)
Community forest	Forest area (natural forests, managed forests and plantations) formally owned by the community (some rules enforced), as percentage of total forest area	[0, 100]	37 (44)
Private forest	Forest area (natural forests, managed forests and plantations) formally owned by private entities (some rules enforced), as percentage of total forest area	[0, 100]	26 (39)
Open access forest	Forest area (natural forests, managed forests and plantations) formally owned by either the state, community or private entities, but no access and usage rules enforced. Percentage of total forest area.	[0, 100]	3 (15)
Required permissions	Percentage of forest products for which permission is required for harvesting	[0, 6]	1.1 (1.3)
Customary rules	Percentage of forest products for which existing customary rules are respected	[0, 100]	46 (49)
Government rules	Percentage of forest products for which existing government rules are respected	[0, 100]	54 (47)
Population change	Population size over past ten years (ratio current population/past population): >1 population growth, <1 shrinkage	[0.5, 8.8]	1.7 (0.84)
Migration	Ratio immigration/out-migration: >1 net-immigration, <1 net-emigration	[0, 560]	13 (55)
In-migration	Percentage of total population that immigrated within the past ten years	[0, 94]	14 (19)
Management	Number of forest management types practiced (e.g. planting and cutting trees, protection of areas or trees, bylaws)	[0, 7]	2.1 (1.6)
Independent variables: self-reported reasons for forest product decline (dummy variables)			
		Yes(Y)/no(N)	#Y/#N
Climate change	Climatic changes, e.g. droughts and less rainfall	Y/N	35/198
Forest clearing	Reduced forest area due to small-scale clearing for agriculture and large-scale projects	Y/N	136/98
Restricted access	Restricted forest access due to people from outside buying land	Y/N	32/201
Harvesting and burning	Timber harvesting, charcoal, brick and bush burning	Y/N	16/217
Legal restrictions	Central state and local restrictions on forest use (e.g. for forest conservation)	Y/N	53/180
Increased product use	Increased use of forest products due to more people (from own or other villages) collecting more	Y/N	175/58
Others	Other self-reported reasons, including poor harvest practices, vermin and changed marketing potentials	Y/N	7/226
Independent variables: self-reported reasons for forest product increase (dummy variables)			
		Yes(Y)/no(N)	#Y/#N
Decreased product use	Decreased use of forest products due to fewer people (from own or other villages) collecting less	Y/N	40/193
Reduced clearing	Less clearing of forests for agriculture	Y/N	25/208
Management change	Changes in forest management, including tree planting	Y/N	45/188
Climate change	Climatic changes, e.g. more rainfall	Y/N	12/221
Increased access	Increased forest access through illegal access to protected areas or improved access rights	Y/N	1/232
Post-clearing supply	Forest clearing increases supply (e.g. fuelwood) or more secondary forest (after forest clearing)	Y/N	6/227

average over all 500 trees. Random forest regression tree procedures provide percent of the variance explained by the model and the mean-squared error (MSE) for each potential tree split. The increase in MSE (%IncMSE) of predictions is the result of a certain variable being permuted (i.e. randomly shuffled values) and thus is a measure of how much the predictive power of the statistical model increases by including this variable. As such, MSE was used to measure the relative importance of the independent variables within the model. The analysis was carried out using the *randomForest* package of the R software (R Development Core Team 2015). All variables included in the analyzes are presented in table 1.

Finally, we fitted a single regression tree for each trend—i.e. one for perceived product increase, and one for perceived decline—to classify homogeneous groups of the original observed data on forest-product changes. The two regression trees were grown and pruned by cross-validation to remove splits that do not substantially decrease the mean square error. We applied a minimum node size of ten; hence all final nodes contain at least 10 data points, i.e. villages. The obtained splits and nodes were used to quantify the combination of drivers resulting in a gradient of little-to-strong change in forest-product availability. For building the single regression trees we used the *rpart* package of the R software (R Development Core Team 2015).

4. Results

4.1. Decreasing forest product availability

Perceived decline of resource availability was the dominating trend, which—except for firewood, medicine and forage in South America—applies to all six product types across the three continents (figure 2 and appendix C). More specifically, the two wood-product categories (timber and fuelwood) perceived the clearest decline across our villages, followed by the forest food category—although these trends differ somewhat across continents. 209 of the 233 villages perceived a decline of at least one forest product. Of these, 87 villages perceived a decline of all their available forest product types. In contrast, availability of at least one forest product increased in 89 villages during the same period according to the informants. This implies that on average 66% of the available products per village were perceived to decline while 16% of the available products were perceived to increase during the same period.

Our most important driver of perceived forest product decline is the increased collection of forest resources by local people; it increases the MSE by 30% (figure 3). Forest clearing, due to both small-scale clearing for agriculture and large-scale projects including plantations and new settlements, is the second-most explanatory factor for the perceived forest-product decline. Among the four different forest-

ownership types, community forest area is the most important predictor for decreasing forest-product availability. Required permissions, climate change and harvesting (timber) and burning (charcoal, brick and bush) are least important in explaining perceived resource availability decline (figure 3). The random forest regression model, which averages the results of the 500 individual trees, explains just over half (52%) of the variance of forest-product decline.

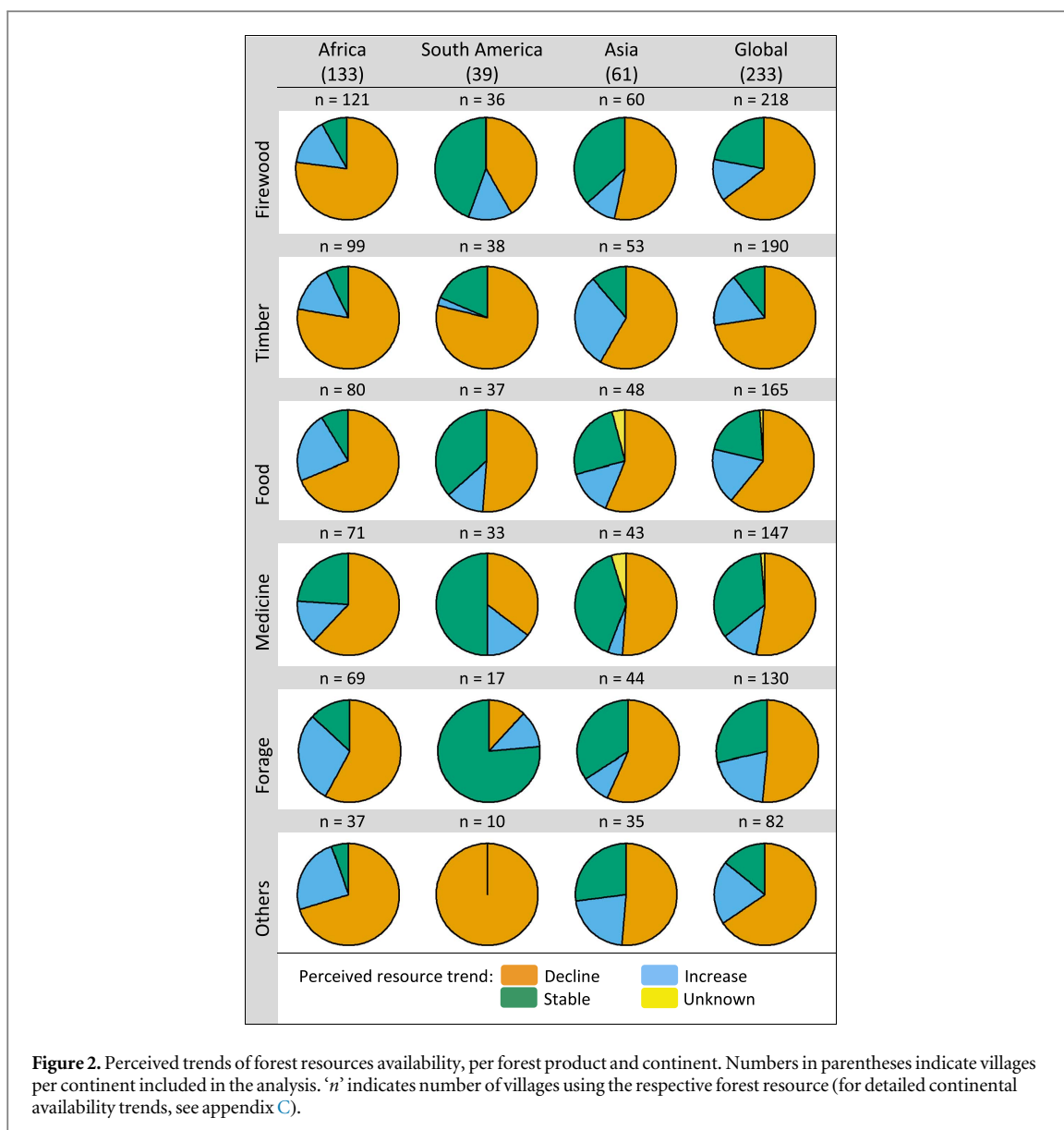
We further identified the combination of factors that determine the intensity of the decline in product availability by growing a single regression tree. Based on the derived split thresholds, indications regarding the processes perceived to fuel the forest-product decline across the pan-tropics can be retrieved. Different combinations of drivers can result in a range of intensities of decline (figure 3 center). Increased forest product use is the first split in the regression tree, meaning that it is the most powerful discriminator between villages with relatively high and low forest-resource decline. In general, increased forest-product use applies to 175 out of 233 villages. The strongest decline is perceived in villages characterized by an increased usage of forest products, a share of community forest area of maximum one third, and immigration. The numerous villages characterized by this combination of drivers (102) have perceived a decline of the available forest products of on average 87% in the past five years. The second-largest group of villages is characterized by an increased forest-product use, a share of community forest area of at least one third, and forest clearing. These characteristics cause on average a decline of 71% of the available forest products. The least decline (with less than one percent) occurs in cases of no increased forest product use by local people, no forest clearing, combined with the absence of legal restrictions with respect to forest use.

Compared to the random forest, the predictive power of the single regression tree is somewhat lower ($R^2 = 0.49$), yet provides explicit splitting conditions pointing to nested factors conjointly driving forest-resource decline.

The predictions of forest-product decline obtained from the single regression tree show varying certainties. The predictions are remarkably high, i.e. having little variance, for the villages with the smallest perceived forest-product decline (figure 4). Apparently, the combination of factors determined by the model explains small product declines well. In contrast, predictions of medium-to-strong product decline show a much lower certainty. Probably, in those cases a variety of factor combinations lead to forest-product decline, which were not fully captured by the regression tree.

4.2. Increasing forest product availability

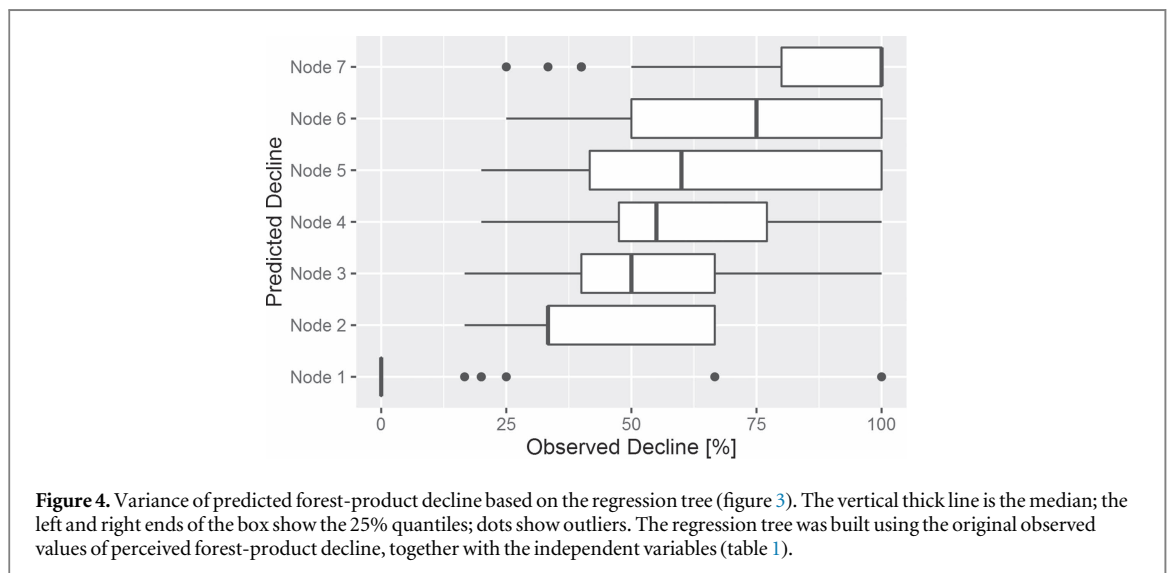
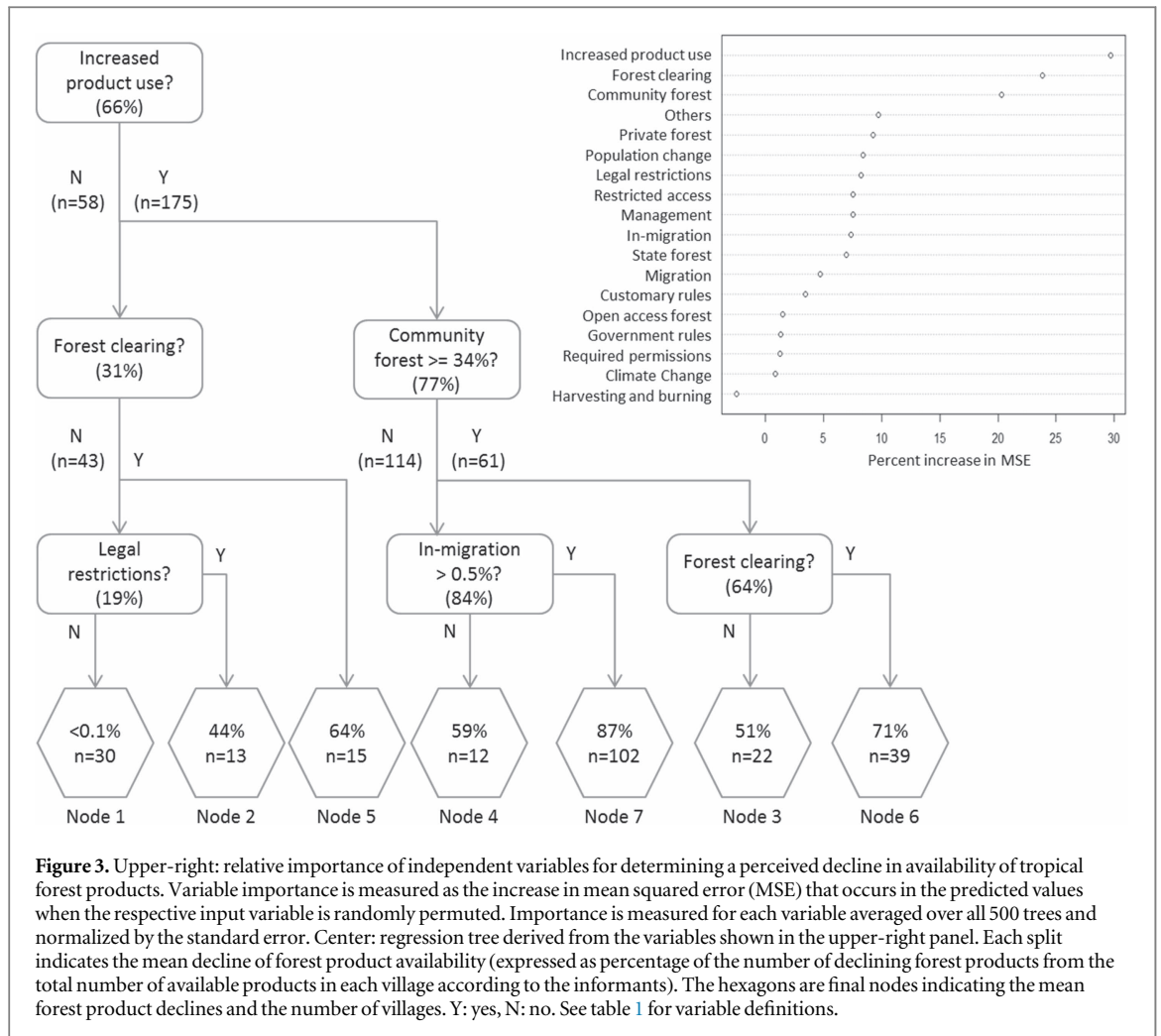
Compared to the perceived resource decline, perceived increases of resource availability exist for at least



one resource in 89 out of 233 villages. The most important factor perceived to support an increase is changes in forest management. Besides, less clearing of forests for agriculture and reduced use of products—mainly because fewer local people collect less, and the usage from large-scale commercial users is reduced—are considered to significantly increase the availability of forest products. These three factors individually increase the MSE by 22%–28% (figure 5). Forest clearing, the second-most important factor for a loss of forest products, also provides opportunities for forest-product increase. Post-clearing product supply, such as fuelwood, is a key predictor of forest-product increase. This reminds us that increased availability is not automatically a sign of more sustainable forest management. Improved forest access, due to both more illegal access of protected areas and improved access rights, in-migration and open access forests are the least important variables, hence contributing least to the perceived increase in availability of tropical

forest products. The random forest regression model explains 63% variance of perceived forest product increase. Hence, predicting the minority scenarios of increases in forest-product availability is more reliable than predicting declines.

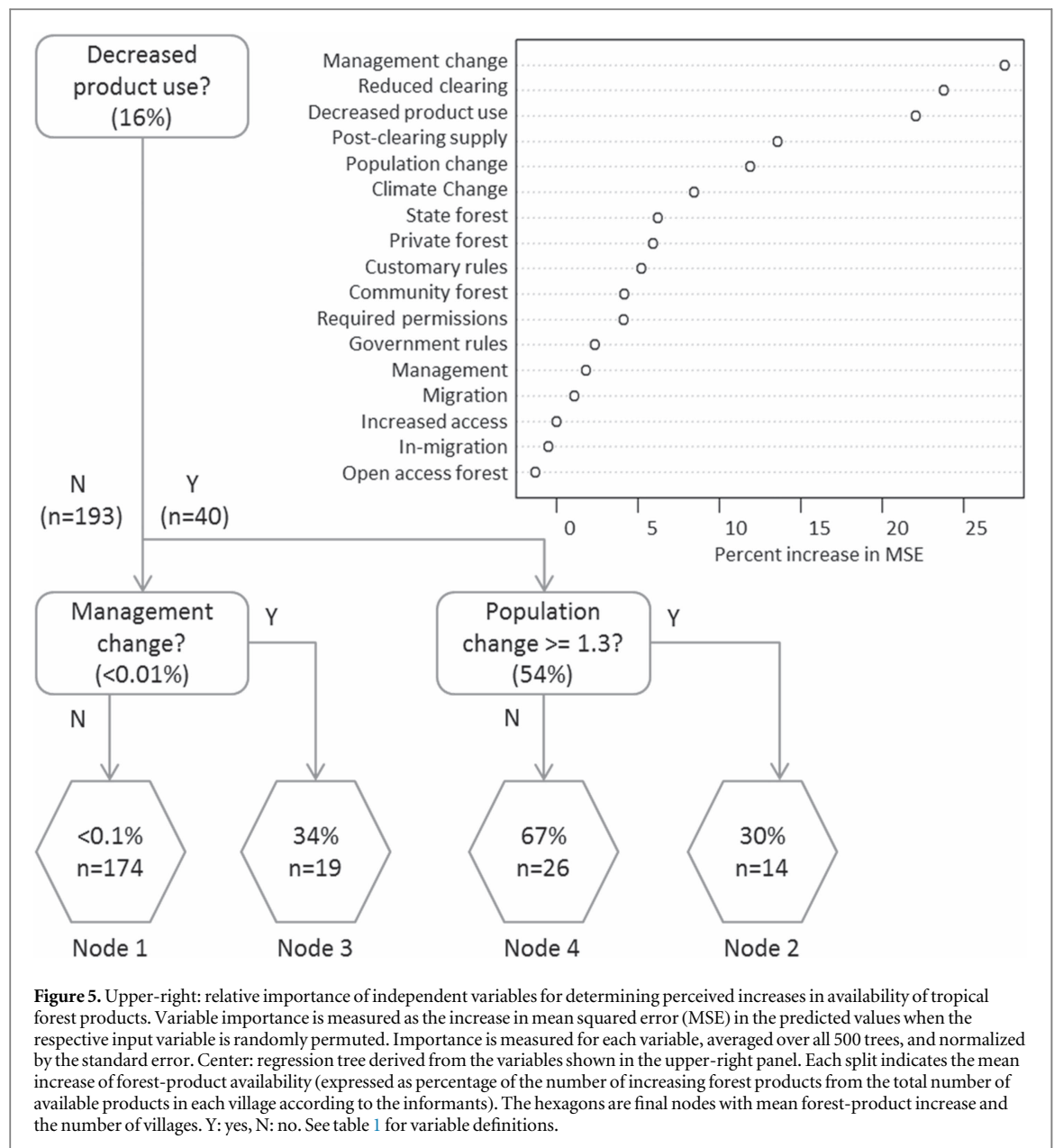
Again, we grew a single regression tree to scrutinize combination of factors determining the intensity of perceived increases in product availability. Figure 5 shows that decreased forest-product use is the first split, i.e. the most powerful discriminator between villages with high versus low forest-resource increase. Yet, decreased forest-product use applied to only 40 villages. The steepest increase was perceived where a decreased use of forest products conjointly occurs with a population growth below 30%. Villages characterized by this combination of factors have perceived an increase of on average 67% of the available products over the past five years. However, this occurs in only 26 of the 233 villages. 78% of villages are characterized by a negligible increase of forest-product



availability (less than 0.1%). The single regression tree explains 62% of the variance of forest product increase (R^2 of single regression tree), hence the predictive power is similar to the random forest model.

Once more, model certainties vary considerably (figure 6). For villages where on average two thirds of the resources are perceived to increase (node 4),

variance is also large, and prediction certainty is low. Hence, these villages are associated with a lower certainty with respect to their predicted resource increase. Analogous to the resource decrease results, in these cases the variety of different combinations of driving factors was not fully captured in the regression tree.

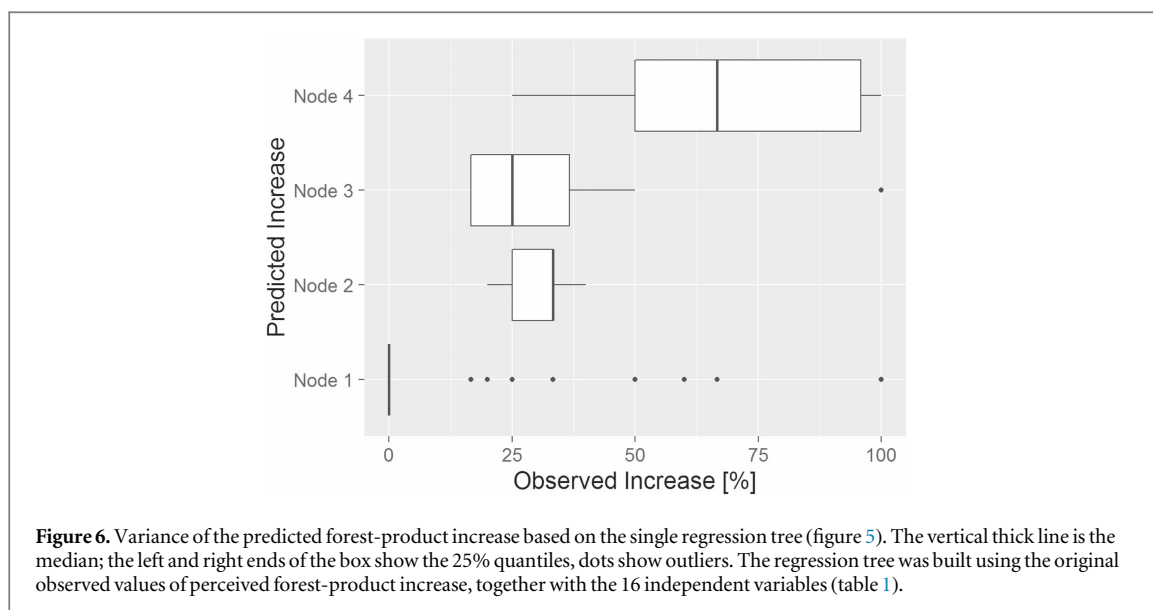


5. Discussion

5.1. Methodological considerations

Comparisons of previous case studies—e.g. systematic quantitative meta-analyses—have been hampered by different study designs, methods and scales (Rudel 2008). Our comparative results, in turn, have the advantage to build on a standardized data collection approach. Our approach does not, however, allow us to infer causal relationships between forest product availability and the independent variables. In addition, we need to critically reflect on the fact that the reported dynamics of forest resources are not objective measurements, but perceptions of local people expressed in village meetings. First, these perceptions may be subject to recall errors over a certain period (five years in our study): the most recently occurring changes and drivers are often better recalled than events farther back in time, which is a well-known disadvantage of

retrospective studies. Cross-checks with independent measurements of forest-product changes could in more detailed case studies be important meaningful supplements for correcting possible biases. However, in our case of a large standardized, global-comparative survey, quite naturally they were not available. We therefore lacked the means to validate such stated perceptions. Second, responses may also reflect cultural biases regarding how sensitive local people are to the perceived dynamics, and how they express them to a visiting research team. Sometimes responses should be considered a vested discourse, for example when local communities bemoan the decline of firewood resources, allegedly due to external resource pressures, because they would like the outside world to restrict external access. Perceptions may also introduce biases regarding the drivers of resource change. For example, in certain cases local people might confuse their knowledge that population has increased with their



notion that resource use has also increased, without being able to prove this based on independent measurements. Furthermore, sampling of opinions of community members may have introduced potential biases regarding the role of the community with respect to resource use, expressed for example in differences regarding forest access and management. Local community members who respond to the survey most likely do not aim at indicting the local community but may tend to be more willing to accuse the outside community. Considering these aspects recording perceptions of resource change and its drivers might introduce biases in the results of the survey. In certain cases such biases may be manifested in shifted variable importance. However, the most important driving factors of resource change (for both decrease and increase of resources) show a distinct importance and we therefore presume that possible biases do not affect our analysis. Since the village surveys provide no means for validating or correcting possible biases our analysis had to consider the survey data being an accurate representation of actual field conditions. In fact, a few studies have tested for biases of self-perceived dynamics of environmental resources. They concluded that reasons for divergence between measured and perceived changes are indeed often associated with (changes in) people's vested interests in certain resources (Meze-Hausken 2004, Amsalu *et al* 2007, Adimassu *et al* 2014). In contrast, if over-exploitation of natural resources has been mostly locally self-inflicted, or even caused by illegal extraction e.g. from a protected area, responses may under-report emerging resource shortages; an aspect that was considered in the PEN survey design (Babigumira *et al* 2014).

5.2. Adaptive behavior of social-ecological systems

The PEN cross-sectional data does not support a study of explicit inter-temporal transitions in the sample

villages. Yet, it provides some clues as to potential factors driving current perceptions of resource change. Whether or not natural resource change will continue depends largely on the extent of local adaptation (Cumming *et al* 2014). Our most important driver of declining availability is the increased local use of forest products. This suggests *per se* a low degree of local adaptation to increasing scarcity—at least so far. Conversely, the smallest forest product declines were perceived in villages without increased forest product use by local people, and in absence of both forest clearing and legal restrictions with respect to forest use. This may indicate, among this minority of cases, a capacity to formulate effective village responses to emerging scarcities in natural resources through the adaptation of use patterns.

Potentially, villages could respond by regulating forest-product access through various institutions and strategies (Armitage 2005, Ostrom and Nagenra 2006). Access to forest products proved to be an important factor for explaining forest product dynamics. Our results show that when at least one third of forest area is owned by local communities, villages are less likely to perceive resource declines than where non-community forest ownership prevails (64% versus 84% perceived product decline). The transition from open access to actively managed community forests often occurs when resource degradation has become substantial, and village institutions are strong enough to enforce rules. Again, our analysis points to a cluster of driving factors here, but we cannot clearly distinguish cause and effects.

5.3. The role of demography

Our analysis singled out population growth as a key factor in explaining forest resource trends. In fact, 91% of our villages faced a growing population from natural population growth and net-immigration combined. The results show that relative population

change is an important factor mainly for perceived increases in availability of forest resources; excluding it from the model reduces the predictive ability of the model by 12%. We identified 40 villages where perceived forest resource increase is responsive to population change, with the strongest rise (67% of the available forest resources) occurring in villages with either population declines or little growth. The majority of villages (85%) experienced immigration within the past ten years; 20% of these villages have an immigrant share of at least 25% of village population. Immigration is moderately important for explaining tropical forest-product decrease. The results show that immigration, controlling for increased product use and community forest area, raises the perceived decline from 59% to 87% of the available forest products. This is in line with findings of several regional and local case studies that illustrate the impact of immigration on forest cover (Geist and Lambin 2002, Carr 2009).

5.4. The role of forest clearing, resource access and management

Change in product use by the local population is a key driver of resource availability; it is the most discriminating factor in both single regression tree analyzes. Increased product use leads, in various combinations with other factors, to a perceived decline of between 51% and 87% of the available forest resources. For the respective villages, we conclude that resource decline has not led to an adaptation of use patterns to counteract trends. Similarly perceived resource decline (64% of the available forest resources) in the absence of increased product use only occurs in case of forest clearing. Overall, forest clearing poses a significant threat for forest products in the villages included in our analysis. As such, forest clearing is the second most important factor for determining forest product changes, in either direction.

Obviously, availability of forest products is linked to the existence of forest. Yet, the incremental effect of deforestation on forest products had been little studied so far, especially in comparative terms. In our study, forest clearing includes both small-scale clearing for agriculture (125 villages) and larger-scale clearing for project development (46 villages). The former is often related to subsistence and cannot be separated from demographic factors (Geist and Lambin 2002). The latter cannot be explained by locally occurring processes alone. In our study, both internally and externally driven forest clearing contribute to the decline of forest product availability. Yet, forest removal also creates opportunities, leveraging fresh supplies of clearance-related products (e.g. fuelwood), and enabling the growth of secondary forests. Post-clearing product supply is the fourth most important contributor to perceived increased forest product availability. Forest management is applied very

differently across all villages. While 28% of the villages do not practice any form of active and deliberate forest management, almost half of all villages apply at least three types of management. Sustainable forest management strategies such as selective logging have the potential to directly provide forest products, and to maintain the forest sustainably. Forest management changes, including tree planting, is the most important factor for determining perceived forest product increase, which can even compensate for continuing resource usage.

6. Conclusions

We studied recently perceived trends of forest product availability in rural developing-country smallholder settings, considering firewood, charcoal, timber, food, medicine, forage and other forest products for a pan-tropical sample of 233 globally distributed villages with forest-product access. The considered perceptions on forest-product changes may be biased due to various reasons, including recall errors, cultural differences regarding sensitivity to perceived dynamics, and particular interests of the community members. Cross-checks with independent measurements of forest-product changes would be important meaningful supplements for correcting possible biases. Yet, for the standardized, globally comparative data used in this study such independent measurements are lacking. An important expedient research step could include quantitative measurements of rates of forest clearing over time based on time series data to be linked to ground measurements of extraction rates of different forest products.

Our results show that the availability of these forest resources can be highly variable. Overall, declining availability of forest resources is the major resource trend, as perceived by 209 villages. In contrast, availability increased for at least one forest product in the perception of 89 villages. In terms of drivers of change, our results show that increased use of forest resources by the local population is seen as the main reason for the decline of tropical forests products. In turn, decreased product use typically leverages an increase of its availability. Population size grew in 211 villages; and forest resources were perceived to increase the strongest in villages with a declining population, or at least low population growth. Furthermore, the strongest resource decrease was perceived in villages with immigration. Local population dynamics thus play a key role in diminishing forest products, thus favoring neo-Malthusian over neo-Boserupian relationships. However, these processes are rarely linear, and would need to be further disentangled in future research. Forest clearing due to both internal (local population) and external forces (large-scale project development) tends to exert considerable influence on resource dynamics. Overexploitation of forest resources

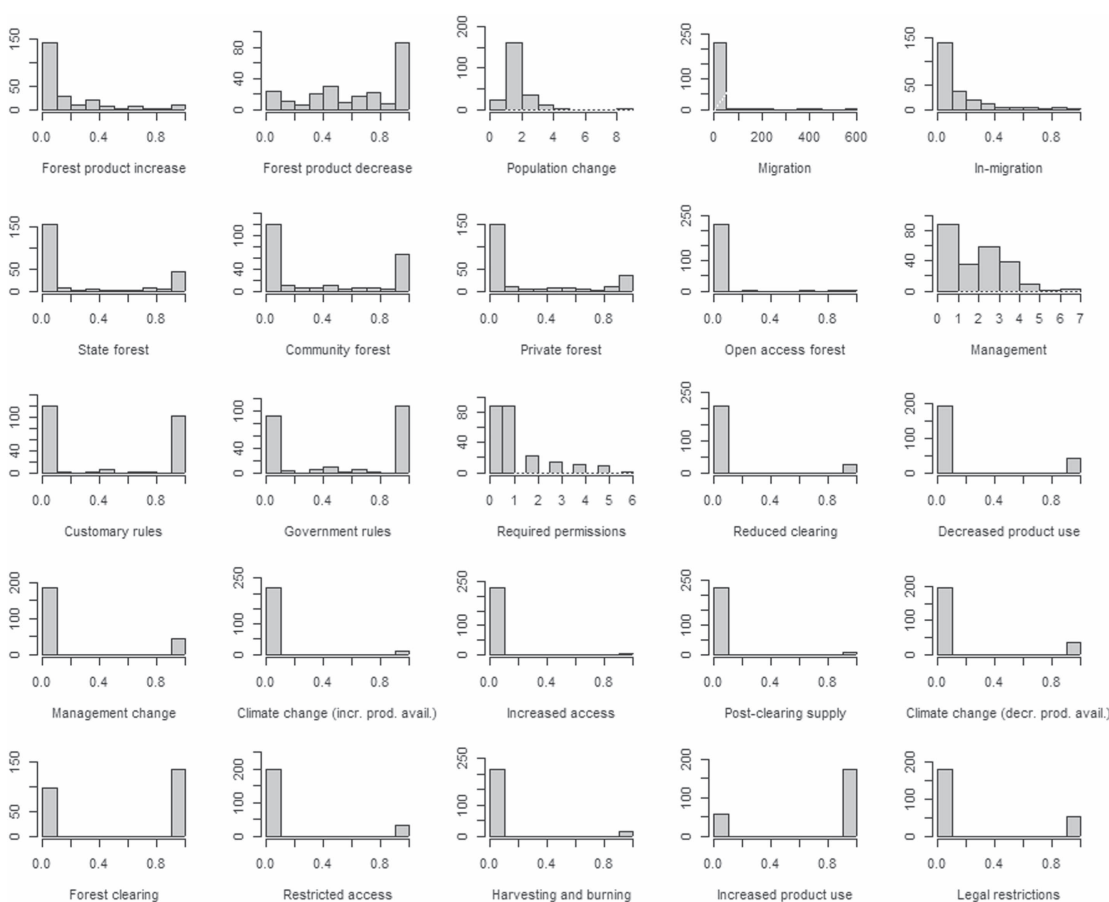
threatens local livelihoods, whenever these depend on forest products. Hence, investigating drivers of resource change is essential for identifying and understanding the resilience of socio-ecological systems, including rural smallholder communities, as addressed in this study.

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Appendix A. Frequency distributions for all variables included in our analysis



Appendix B. Pearson correlation coefficients for all independent variables included in our analysis. Significant values ($p < 0.05$) are bold

Population change																						
0.25	Migration																					
0.5	0.51	In-migration																				
0.09	-0.04	0.02	State forest																			
-0.11	0.02	-0.01	-0.47	Community forest																		
0.02	0.06	0	-0.36	-0.38	Private forest																	
0.11	0	0.02	-0.07	-0.13	-0.13	Open access forest																
-0.19	-0.11	-0.17	0.02	0.29	-0.13	-0.12	Management															
-0.1	-0.08	-0.03	-0.15	0.29	-0.03	-0.11	0.17	Customary rules														
-0.1	-0.04	-0.05	0	0	0.05	-0.11	0.06	0.29	Government rules													
-0.15	-0.05	-0.03	-0.08	0.22	0	-0.06	0.21	0.13	0.33	Required permissions												
-0.05	-0.01	0.01	-0.03	-0.02	0.11	-0.04	0.22	0.01	0.07	0.27	Reduced clearing											
-0.25	-0.05	-0.19	-0.18	0.34	-0.1	-0.06	0.16	0.06	-0.02	0.38	0.24	Decreased product use										
-0.14	-0.06	-0.17	-0.18	0.18	0.09	-0.07	0.18	0.15	-0.05	0.3	0.27	0.53	Management change									
-0.07	-0.05	-0.08	-0.14	0.05	0.09	-0.04	-0.06	0.13	0.03	0.04	0.13	0.26	0.18	Climate change (incr. prod. availability)								
-0.04	-0.02	-0.03	-0.04	0.02	0.04	-0.01	0.08	0.07	0.07	0.04	-0.02	0.16	0.14	-0.01	Increased access							
0.04	-0.03	0.03	-0.11	0.16	-0.01	-0.03	-0.11	0.09	-0.12	-0.1	0.03	0.01	-0.08	-0.04	-0.01	Post-clearing supply						
0.1	0.06	0.1	-0.08	0.18	-0.09	-0.01	-0.11	0.07	0.03	0.02	0.04	-0.05	-0.04	-0.09	-0.03	0.23	Climate change (decr. prod. availability)					
0.21	0.12	0.18	0.07	-0.19	0.3	-0.04	0	-0.12	0.12	0	-0.06	-0.3	-0.09	-0.05	-0.08	-0.09	0.02	Forest clearing				
-0.02	0.07	-0.03	0.09	-0.21	0.1	-0.02	-0.04	-0.11	0.04	-0.13	-0.02	-0.14	-0.13	0.04	-0.03	-0.07	0.11	0.17	Restricted access			
0.03	-0.01	0.11	-0.18	-0.01	0.23	-0.06	-0.16	0.04	-0.02	-0.08	-0.1	-0.12	-0.09	0.02	-0.02	0.06	0.02	0.12	-0.11	Harvesting and burning		
0.17	0.01	0.11	-0.08	-0.19	0.19	0.05	-0.24	-0.07	-0.05	-0.13	-0.07	-0.32	-0.21	-0.04	-0.12	0.09	0.15	0.35	-0.02	0.11	Increased product use	
-0.13	-0.07	-0.05	-0.01	0.03	-0.07	-0.05	-0.16	0.02	0.06	0.12	-0.11	0.12	0.16	0.05	0.13	0.05	-0.04	-0.13	0.11	-0.01	0.04	Legal restrictions

Appendix C. Trends of forest resources availability per forest product and continent

Forest product	Trend of resource availability	S. America (39 villages)		Africa (133 villages)		Asia (61 villages)		Total (233 villages)	
		#	%	#	%	#	%	#	%
Firewood	Resource use	36	92,3	121	91,0	60	98,4	217	93,1
	Decline	15	41,7	94	77,7	32	53,3	141	65,0
	Increase	5	13,9	18	14,9	6	10,0	29	13,4
	Stable	16	44,4	10	8,3	22	36,7	48	22,1
Timber	Resource use	38	97,4	99	74,4	53	86,9	190	81,5
	Decline	30	78,9	77	77,8	31	58,5	138	72,6
	Increase	1	2,6	15	15,2	16	30,2	32	16,8
	Stable	7	18,4	7	7,1	6	11,3	20	10,5
Food	Resource use	37	94,9	80	60,2	48	78,7	165	70,8
	Decline	21	56,8	55	68,8	27	56,3	103	62,4
	Increase	5	13,5	18	22,5	7	14,6	30	18,2
	Stable	15	40,5	7	8,8	12	25,0	34	20,6
	Unknown trend	0	0,0	0	0,0	2	4,2	2	1,2
Medicine	Resource use	33	84,6	71	53,4	43	70,5	147	63,1
	Decline	12	36,4	44	62,0	22	51,2	78	53,1
	Increase	5	15,2	10	14,1	2	4,7	17	11,6
	Stable	17	51,5	17	23,9	17	39,5	51	34,7
	Unknown trend	0	0,0	0	0,0	2	4,7	2	1,4
Forage	Resource use	17	43,6	69	51,9	44	72,1	130	55,8
	Decline	2	11,8	40	58,0	25	56,8	67	51,5
	Increase	2	11,8	20	29,0	4	9,1	26	20,0
	Stable	13	76,5	9	13,0	15	34,1	37	28,5
Other resources	Resource use	10	25,6	37	27,8	35	57,4	82	35,2
	Decline	10	100,0	26	70,3	19	54,3	55	67,1
	Increase	0	0,0	9	24,3	8	22,9	17	20,7
	Stable	0	0,0	2	5,4	10	28,6	12	14,6

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