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Interplay of governance elements and their effects on deforestation in tropical landscapes: Quantitative insights from Ecuador

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ABSTRACT

After state-centered and market-centered approaches have driven international development cooperation activities in previous decades, improved governance has now come into the focus as a means to help reversing global trends of tropical deforestation. Yet, "good governance" remains a normative, broad and often underspecified concept consisting of a wide range of elements and implicit value judgements. Specific knowledge is missing on the relative importance of single elements, on their interdependencies and their specific effects. Following an analytical approach, we aimed to investigate if single governance elements affect each other and whether they relate to decreasing deforestation. We conducted a quantitative field study in twelve selected landscapes across 160,000 ha of tropical lowland forest in Ecuador. We mapped governance arrangements and land use in participatory exercises. The performance of single governance elements including tenure, forest management practices, law enforcement, institutions, and participation was quantified based on the governance assessment framework of the World Resource Institute. We assessed context information and used satellite based deforestation data. Principal component analysis showed that all governance elements loaded positively on the first axis. This shows that specific governance elements acted conjointly. They are in general not antagonistic, but interact positively and might reinforce each other. Policy and development work may therefore focus on a smaller number of well-selected governance elements. High performance of specific governance elements, in particular tenure and participation was linked to reduced deforestation. This supports the notion of a number of governance elements as being indeed "good" for low deforestation. This functional understanding draws a more differentiated picture for single governance elements and supports outcome oriented decisions instead of value-oriented principles that underlie "good governance". Direct deforestation drivers such as agriculture and infrastructure explained larger shares of deforestation as compared to governance. A number of conclusions and recommendations for the specific governance situation in tropical lowland forests of Ecuador are given.

1. Introduction

1.1. Background

Even though the pace of net forest loss has slowed, the area of the world's forests continues to decrease. The rate of annual net loss of forest has slowed from 7.8 mio hectares in the 1990s to 4.7 mio hectares between 2015 and 2020 (FAO, 2020). The largest

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loss of forest area still occurs in the tropics particularly in Africa and South America. Improved governance has come into the focus as a promising mechanism to globally reverse this trend. In international forest policy, governance is increasingly taken into account (Singer & Giessen, 2017), even though it is clear that forest governance alone is certainly not sufficient to address drivers of deforestation and degradation (Larson, 2011; Busch & Ferretti-Gallon, 2017). Governance is one out of six UN Forest Goals (UN, 2019) and plays a core role in international forest programs, such as REDD+ ("Reducing Emissions from Deforestation and Forest Degradation") and FLEGT ("Forest Law Enforcement, Governance and Trade") to which it even lends its name.

The concept of governance has, in part, evolved from a fundamental problematization of the role and function of the state, starting in the 1970s (Ansell & Torfing, 2016). This resulted in a transition from state-driven governments to multi-actor governance (Arts, 2014). Such governance is understood to steer society and the economy through collective action (Torfing et al., 2012). In contrast to a normative "good governance" concept (Arts, 2012; Ansell & Torfing, 2016), analytical governance approaches rely on the mere reflection of the processes and their explanation (Giessen & Buttoud, 2014). But as forest governance comprises a multitude of different elements, an analytical governance approach needs an understanding of how different governance elements are related, how they affect each other and which of them are of specific relevance for achieving predefined aims. In practice, governance elements and numerous forest governance indicators are specified by handbooks, frameworks and toolboxes (Kishor & Rosenbaum, 2012; Davis et al., 2013; de Graaf et al., 2017). Analytical governance understanding is challenging due to the large number of governance elements and the decisive role of the local contexts (Wehkamp et al., 2018). First insights into governance functioning have been provided by Fischer et al. (2020) based on review data. Further substantiation based on empirical field data is now required.

In order to value the importance and relevance of different governance elements, it is necessary to relate them to outcomes, such as reduced deforestation in the tropics. Geist and Lambin (2002) conceptualize that proximate drivers have effects on deforestation and are themselves affected by governance which is understood as an underlying cause. There are numerous case studies that analyze effects of single governance elements on deforestation. Reviews based on such case studies have been published (Wehkamp et al., 2018; Fischer et al., 2020). However, a comprehensive analysis based on empirical field data is hardly available until today. Specific analyses on landscape level are needed in order to research larger areas where agriculture, forestry, and other productive land uses compete with environmental and biodiversity goals (Sayer et al., 2013).

With an annual forest loss rate of 0.6% calculated for the period 1990–2015 (FAO, 2015), Ecuadorian forests are among those with highest deforestation rates in South America. The main drivers of deforestation in Ecuador are agricultural expansion with crops produced for subsistence use, domestic and international markets as well as land demand for pastures. Road infrastructure provides access to remote areas and is frequently provided by logging operations, oil mining industries as well as governmental investments. Commercial crop plantations play a regionally important role, like e.g. palm oil plantations in the province of Esmeraldas (Castro et al., 2013; Sierra, 2013; Nepstad et al., 2021).

Forest resources of Ecuador are under the principal competence of the state (ACE, 2008). The largest share of state forests falls under the patrimony of natural areas (PANE). This is part of the national system of protected areas '*Sistema Nacional de Areas Protegidas*' (SNAP) which covers approximately 20% of the Ecuadorian territorial surface. Private individuals or organizations can obtain land titles if possession and production is documented over a minimum period of five years. But based on customary rights, private farms and communal settlements also exist on non-titled lands (Holland et al., 2014). Settlers introduced intensified agricultural practices including cattle ranching (Pichón, 1997; Rudel et al., 2002) and until today often benefit from road infrastructure created by logging and mining enterprises as well as public and non-public oil roads (Baynard et al., 2013). Indigenous populations occupy territories corresponding to 65% of the Ecuadorian forests (Palacios, 2005) (Morales et al., 2010), with large parts located in SNAP areas. Traditionally indigenous communities leave parts of their forests unmanaged as reserve after having assigned portions of individual land to each of the members. The ultimate goal is to reserve land for future generations and future production (Holt & Bilsborrow, 2004; Izurieta et al., 2014). In 2008, the Ecuadorian government launched the Socio Bosque program, which applies to private and communal forest owners and gives direct monetary incentives for the conservation of vulnerable ecosystems. The program is based on 20-year legally binding conservation contracts including biannual payments as partial compensation for restrictions from altering the forests. 1.6 mio ha are currently under Socio Bosque, annual payments for 2018 amounted to 10.5 mio USD and were distributed to 175.000 beneficiaries (MAE, 2018b).

1.2. Aims

This study aims to empirically analyze forest governance functioning and to quantify governance effects on deforestation. It seeks to disentangle functional relations between main governance elements in order to find out if specific elements are determining overall governance and its effects on deforestation more than others. Governance effects on deforestation are studied together with direct (proximate) deforestation drivers that are themselves hypothesized to be affected by governance as an underlying cause. The results aim to contribute to an outcome oriented analytical governance understanding which can justify, challenge or moderate measures that are until now based on a normative "good governance" approach.

Methodologically the study implements an empirical field study at landscape level. This implies a spatial analysis of larger areas. The study is carried out in tropical lowland forest areas of Ecuador. Insights and recommendations for the development of the study area are presented.

2. Theoretical foundations

2.1. Governance theory and definition

The main theoretical basis of forest governance has been claimed to consist of two mainstream models: rational choice and neo-institutionalism, otherwise described as agency – structure concept, which provides a theoretical basis to better understand and describe governance approaches (Arts et al., 2014). The agency approach postulates that it is mainly self-interested actors with their specific motivations, intentions, goals, actions and resources, which take active agency and, hence, drive land use decisions. On the other side, structural elements like laws, regulations, plans, cultural conventions and norms provide a frame for land use decisions (Archer, 2003). Specifically (Ostrom, 1990) points to the fact that institutions impact behavior through rules, norms and incentives in order to prevent a tragedy of the commons. North (1991) emphasizes the importance of informal institutions vis a vis the formal ones. It has to be taken into account that usually neither structure nor agency alone drive human behavior. Giddens (1984) formulates that agents - groups or individuals - draw upon structures to perform social actions but at the same time structure is the result of these social practices.

Numerous definitions have been proposed for forest governance (Larson & Petkova, 2011; Broekhoven et al., 2012; Davis et al., 2013; Giessen & Buttoud, 2014; de Graaf et al., 2017; Mansourian, 2017). The recent definitions all understand governance as a broad and comprehensive concept that goes far beyond governments and that is centered around decisions on forest management (Larson & Petkova, 2011; Broekhoven et al., 2012). Following Giessen and Buttoud (2014) "*forest governance comprises a) all formal and informal, public and private regulatory structures*, i.e. *institutions consisting of rules, norms, principles, decision procedures, concerning forests, their utilization and their conservation, b) the interactions between public and private actors therein and c) the effects of either on forests*". This definition explicitly mentions structural aspects in its first part and describes agency related aspects as interactions of different actors in the second part. It further relates governance to effects on forests, which is in line with the aims of this study. This definition thus provides the basis for the present study.

2.2. Interlinkages of governance elements and their effects on forests

Whatever definition applied, governance comprises a multitude of different elements specified by numerous indicators. Handbooks and toolboxes list governance indicators but without substantiation of functional links or effects for each of them (Worldbank, 2006; Kishor & Rosenbaum, 2012; Davis et al., 2013; de Graaf et al., 2017). IFRI (2011) provides conceptualizations of governance element interactions and a methodology for field assessments based on Ostrom (1999) but is mainly based on qualitative descriptions. Also CIFOR (2015) and Ravikumar et al. (2015) aim at a descriptive approach. Systematic studies that quantify functional relations based on these approaches are missing. First quantitative insights into governance functioning have been provided by Fischer et al. (2020) based on review data. Our study relies on the forest governance assessment framework of the World Resource Institute (Davis et al., 2013). It extends the methodological approach of Fischer et al. (2020) to the field level.

Existing results on governance effects show positive relations between improved governance and reduced deforestation. Scholars have produced an increasing number of (i) case studies analyzing governance effects on deforestation in field studies (Andersson et al., 2014; Schusser et al., 2015; Subhan Mollick et al., 2018) (ii) statistical evaluations of governance effects using regional or global panel data sets (Umemiya et al., 2010) and (iii) reviews of existing research results (Bhagwat et al., 2017; Wehkamp et al., 2018; Fischer et al., 2020). The prevailing conclusion in such studies is that improved forest governance at least contributes to reduced deforestation. However, quantitative relations of governance indicators to proximate drivers remain open and effects are reported for individual governance elements only. It is not clear, which are the most decisive governance elements with respect to deforestation outcomes and how elements are functionally related in their effects.

2.3. Conceptual framework

Taking into account the definition of Giessen and Buttoud (2014) we conceptualize governance as being based on (A) multiple actors and (B) structures including formal and informal rules of forest-related decisions and their implementation (Fig. 1). These two main governance components reflect the agency – structure concept, which provides a theoretical basis to better understand and describe governance approaches (Arts et al., 2014; Fischer et al., 2020). In addition to these two components we take into account (C) interactions between actors, (D) interactions between actors and structures and (E) the effects of either on forests in order to compose a comprehensive governance framework.

In order to specify actors, structures and interactions we use a set of governance elements as described by the World Resource

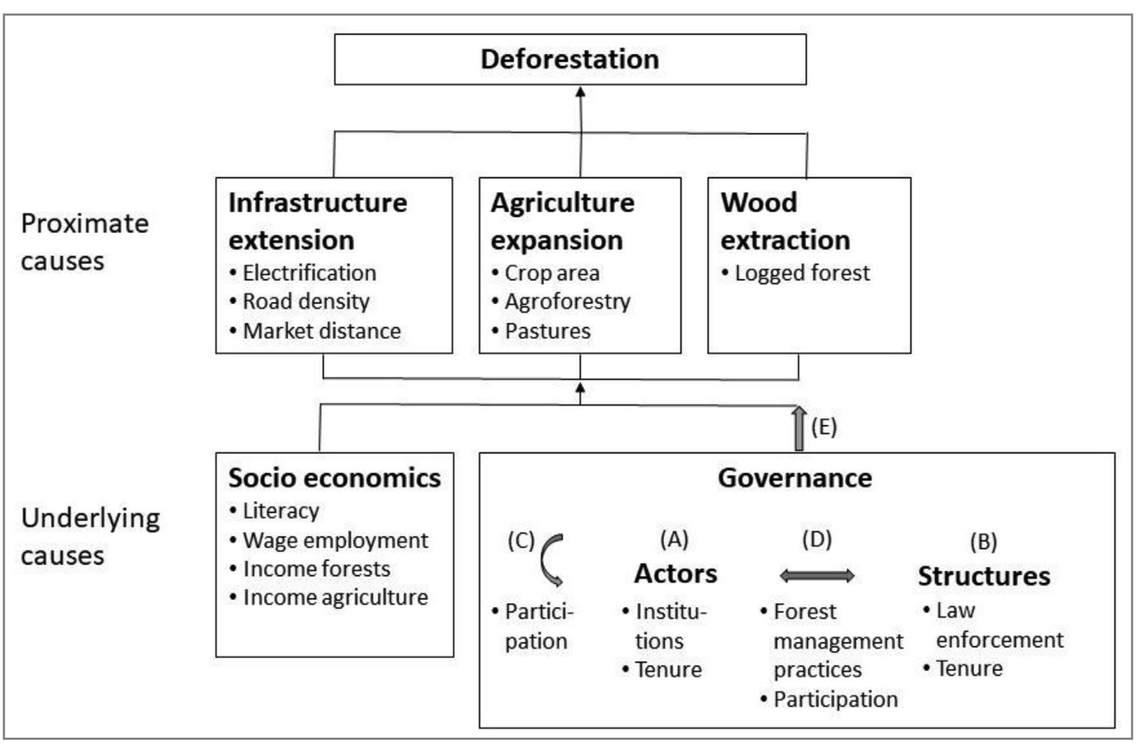

Fig. 1. Conceptual framework underpinning the study. Adapted from Geist and Lambin (2002) and amended by the governance components: (A) actors, (B) structures (C), interactions between actors, (D) interactions between actors and structures, (E) the effects on forests. Bullet points represent governance elements and other variables assessed within the study.

Institute (Davis et al., 2013). We relate governance elements either to one specific component (e.g. *institutions* represent an actor) or in other cases to several governance components (e.g. *tenure* refers to actors and rules, *participation* refers to interactions between actors and to interactions between actors and structures).

Like socio-economic factors, forest governance is an underlying cause i.e. a fundamental force that underpins the proximate drivers of deforestation and forest degradation (Turner et al., 1993; Geist & Lambin, 2001; Geist & Lambin, 2002; Hosonuma et al., 2012). Therefore, we incorporate selected proximate drivers of deforestation (Fig. 1). The proximate drivers are human activities that directly affect the environment or forest. In our study we consider agricultural expansion, wood extraction and extension of infrastructure.

3. Methods

3.1. The study area in Ecuador

The study was conducted in the provinces of Esmeraldas (Northwestern Coast), Napo, Pastaza and Orellana (Central Amazon). These provinces accounted for 27% of the net deforestation of Ecuador in the years 2014–2016 (MAE, 2018a). For our research, we selected twelve landscapes within the larger LaForeT project (www.la-foret.org). Each landscape covers approximately 100 km^2 and is situated within one parish ('*parroquia*') to ensure homogeneous formal administration (Fig. 2). Each landscape is placed to cover a gradient of typical forest cover development and to include different phases of forest transition (Mather, 1992; Grainger, 1995; Hosonuma et al., 2012). Half of the landscapes include conservation areas of PANE or Socio Bosque as two prominent forest conservation schemes in Ecuador, whereas the other half does not include such restricted areas. All landscapes are located at elevations of below 1100 m asl. within the natural vegetation zones of evergreen lowlands or evergreen foothill forests (MAE, 2013) (Table 1).

Table 1
Key characteristics of landscapes studied (*FC2016 is native forest cover % within the landscape boundaries in 2016, calculated from (MAE, 2017b). AFCC (in brackets) is the mean annual native forest cover change within the landscape for the period 2008–2016 (MAE, 2016; MAE, 2017a)).

Number (Fig. 2)	Landscape name	Total landscape area [ha]	FC2016 (AFCC)*
1	San Francisco Ónzole	10.615	62,16% (−0,50%)
2	Santo Domingo Ónzole	10.010	88,48% (−0,34%)
3	Tabiazo	8.800	31,07% (+0,96%)
4	Cube	11.937	23,92% (−3,46%)
5	Chontapunta	16.407	50,17% (−1,27%)
6	Ahuano	18.919	65,03% (−0,17%)
7	Carlos Julio Arosemena	13.458	57,60% (−0,99%)
8	Rukullakta	15.878	71,52% (+2,31%)
9	San Jose de Dahuano	13.010	49,37% (−1,73%)
10	Avila Huirino	16.128	61,83% (−0,87%)
11	Arajuno	16.136	81,84% (−0,71%)
12	Canelos	12.148	72,62% (−0,36%)

3.2. Data collection

Data collection was carried out through participatory exercises (see Section 3.2.1) and included mapping of governance arrangements (Section 3.2.2) for which governance performance was assessed (see Section 3.2.3), as well as land use mapping (see Section 3.2.4). Key informant interviews were conducted for socio economic and infrastructure data (see Section 3.2.5). Deforestation was calculated based on satellite data and served as target variable in the models (see Section 3.2.6). Field data were collected in an extensive field campaign with a staff of 10 persons in the context of the LaForeT project (www.la-foret.org) during 18 months in the years 2016 and 2017.

3.2.1. Mapping exercises for governance and land use information

We carried out participatory mapping (Elwood & Ghose, 2011; Martin et al., 2012; Freund et al., 2016). Two workshops were carried out in each landscape with between 15 and 25 community and stakeholder representatives. In these workshops two sets of maps were produced within focus group discussions (Nyumba et al., 2018), each of them fully covering each landscape: one map for governance arrangements and one for land use. Mapping was carried out on printouts of Google satellite images of approximately 1.5 m*1.5 m. Unclear cases were clarified in subsequent field visits

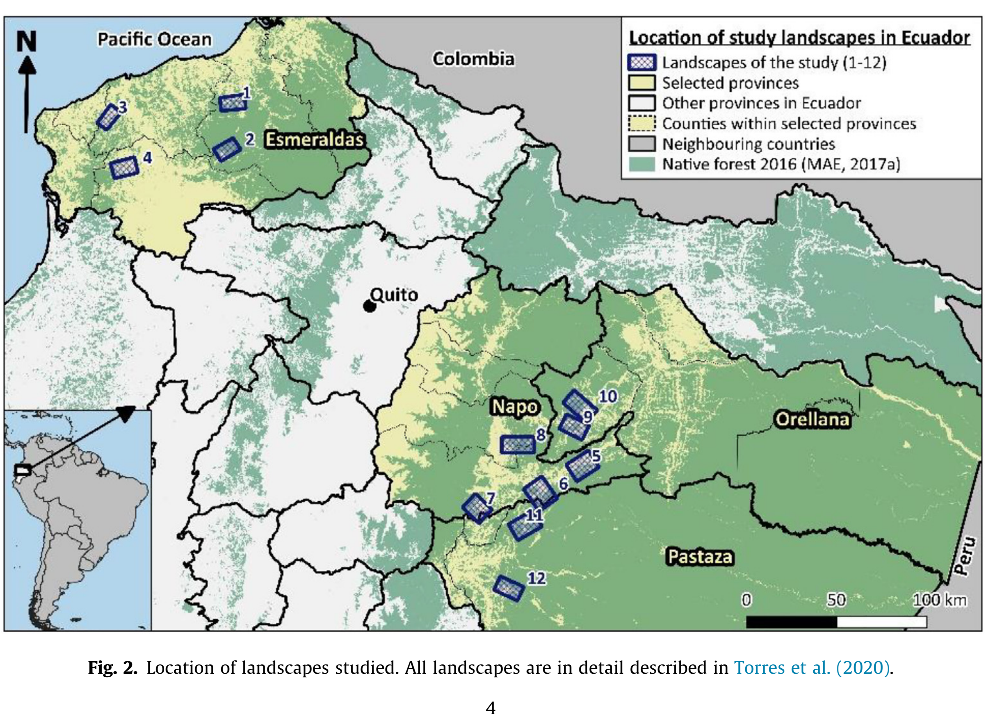

Fig. 2. Location of landscapes studied. All landscapes are in detail described in Torres et al. (2020).

together with the project manager. All mapped information was digitized using QGIS 2.18 (QGIS, 2018).

3.2.2. Classification and delineation of governance arrangements

Governance arrangements were defined as spatial units with a homogeneous constellation of governance components (see Section 2.3). During scoping visits we identified 6 different governance arrangement types based on an own categorization related to the conditions in the research area. They comprised

1. Communal land, with or without land title, excluding conservation areas. In the research area, communal lands were coinciding with indigenous land ownership.
2. Individually owned land, with or without land title. In the research area, individual land predominantly coincided with farms owned by settlers.
3. Indigenous reserves as traditional form of land conservation on communal indigenous land.
4. Socio Bosque conservation areas on communal indigenous land.
5. State protection areas (PANE).
6. Others (including private enterprises, research areas, land with unidentifiable/unassessable governance and ownership, cities, airports, large infrastructure)

In total, we mapped 139 governance arrangement patches. These patches covered the complete area of all 12 landscapes, i.e. 163,627 ha. We excluded 18 patches (18,444 ha) with the category "6. Others" from further evaluations. It was not possible to establish contacts to private enterprises engaged with logging activities in the landscapes.

3.2.3. Governance elements and performance

During the focus group discussions we assessed governance performance for patches of single governance arrangements by applying the forest governance assessment tool of the World Resource Institute (Davis et al., 2013). The assessment tool postulates that predefined elements should be contextualized in order to better fit local needs. After scoping trips in the study region we selected five governance elements namely (i) tenure security, (ii) forest management practices, (iii) law enforcement, (iv) institutions, and (v) participation in public decision making. These elements are among the most frequently researched governance elements in global literature (Fischer et al., 2020), represent different governance components (see Section 2.3) and thematic areas as specified by Davis et al. (2013). Each of the five governance elements was assessed by three indicators through Likert scores (Likert, 1932) on a scale from 0 (not existing), 1 (very low) to 5 (very high). Definitions of governance elements and indicators are provided in Annex 1.

Considering available project resources and time that stakeholders were able to make available for the workshops, governance performance could be scored for 25 governance arrangement patches that were selected from the 139 patches covering in total 50,115 ha and spread across all 12 landscapes. This resulted in mostly two patches with governance performance assessments per landscape. We selected all available Socio Bosque and PANE patches for the assessment of governance performance scores as these categories were less frequently occurring. Governance performance of the remaining governance arrangements was assessed on randomly selected patches in the landscapes. We used the 25 patches with governance performance assessments to extrapolate governance performance scores to additional patches. We extrapolated within the same or neighboring landscapes where patches were comparable in terms of land use and governance mechanisms. This allowed to extrapolate governance performance scores to additional 59 patches. which increased the number of patches with governance information to 84 covering 99,563 ha.

3.2.4. Land use types

Land use is considered a decisive context factor influencing deforestation. We classified it adapting and simplifying (Di Gregorio & Jansen, 2005). Seven land use types were mapped in all landscapes in participatory exercises during the workshops. They included (i) primary forests (ii) secondary succession forests, (iii) secondary forests after timber harvest, (iv) crop lands, (v) pastures, (vi) agroforestry systems, (vii) others. In all, we mapped 1136 land use patches covering the complete area of the 12 landscapes. Merging governance arrangements and land use types in the GIS allowed to calculate the percentage of each governance arrangement patch covered by different land use types.

3.2.5. Socio economic and infrastructure context

During the field phase we established contacts to the communities in the landscapes. From over 70 communities we randomly selected three community leaders per landscape and conducted key informant interviews. Seven key variables were derived from the interviews: (i) percentage households with electricity, (ii) percentage of population that can read/write, (iii) km from community center to nearest general market, (iv) km from community center to nearest agricultural market, (v) hourly rate for wage employment of an unskilled worker in US Dollars, (vi) mean percent of household income from forests, (vii) mean percent of household income from agriculture.

We determined total road length within each governance arrangement patch by summing up all the terrestrial means of transportation, including highways, roads, paths and railways as obtained from shapefiles of public sources (IGM, 2018; OSM, 2018). The road density [km/ha] was then calculated by dividing the total road length [km] by the total area of each specific governance arrangement patch [ha].

3.2.6. Deforestation

The net loss of native forest (deforestation) between years 2008 and 2016 was determined for the area of each of the 139 mapped governance arrangements based on publicly available data from the Ecuadorian Ministry of Environment (MAE, 2015; MAE, 2017c). Based on automatic classification of LandSat imagery using RapidEye scenes and ground control points as validation sources (MAE-MAGAP, 2015), this data set provides spatially explicit land cover information. The underlying LandSat imagery is partly the same as used by Hansen et al. (2013), however with more intensive ground control point validation carried out by the Ecuadorian Ministry of Environment. We calculated the loss of native forests ('*bosque nativo*') between 2008 and 2016 in hectares relative to the total area of each delineated governance arrangement patch and divided it by the number of years in order to derive mean annual deforestation rates.

3.3. Statistical analysis

In order to compare governance scores we used the non-parametric Wilcoxon test comparing multiple pairs. We applied this non-parametric test because in a number of cases the assumption of normality in the data was not given (Siegel, 1988). We pooled Socio Bosque patches and indigenous reserves because sample sizes of five Socio Bosque and two indigenous reserves patches were too low for meaningful statistics. In addition, they showed very similar governance which justified pooling (mean governance for indigenous reserves was 3.4 and for Socio Bosque 3.8). We excluded PANE areas from tests comparing the means as the sample size of two patches was too low. Mean governance was calculated as the mean of the five single governance elements per patch.

Principal component analysis (PCA) (Dunteman, 1989) reduces the dimensionality of a multivariate data set by producing linear combinations (principal components) of the original variables (e.g. governance indicators) that summarize the predominant patterns in the data (Peres-Neto et al., 2003). We calculated a PCA for the 25 governance arrangement patches with field governance assessments in order to identify independent gradients within the governance data and their correlations to original governance variables.

We used multivariate regression analysis with backward elimination in order to check for potential relationships between deforestation (target variable) and infrastructure, socio-economic, land use as well as governance variables (predictors) for all 84 patches with assessed or extrapolated governance information. As we could not determine a statistically significant difference in annual deforestation between patches with assessed and extrapolated governance scores, a bias due to the method of determining governance performance can be excluded. From the original 84 patches that we used as basis for regression analysis, we removed four patches with more than three times standard deviation of deforestation. Our models satisfy the assumptions of normality (Shapiro-Wilk-W test, p-values always >*0.5*), and no multicollinearity (VIF < 5, (PennState, 2019)). We assured for homoscedasticity applying the Breusch-Pagan test.

As independent variables were measured at different scales, we conducted Z score standardization to normalize data. Land use variables were all highly intercorrelated as indicated by variance inflation factors (VIF) above 10; we thus only used percentage of crops to characterize land use, which we interpret as indictor for agricultural land use intensity. Within backward selection, we successively removed explanatory variables that were not significant and that did not decrease the r^2. Within our nested survey design, governance arrangement patches are clustered in 12 landscapes. We therefore checked for the effect of landscapes by including the landscapes as a dummy variable. We also checked for an effect of PANE/Socio Bosque being present or absent in the landscapes. Both effects were not significant.

We used Likert scores and their means as continuous values in quantitative statistical approaches including comparison of means, principal component analysis and multiple regression analysis following Manley (2005). All statistical evaluations were carried out using the statistical software package of JMP 12 (SAS, 2015).

4. Results

4.1. Mean governance performance in the landscapes

Socio Bosque patches and indigenous reserves in general had highest governance scores (Table 2). These significantly differed as compared to individually managed patches. This overall difference was based on a significant difference of governance performance for tenure and participation between Socio Bosque/indigenous reserves on one side and communal and individually managed patches on the other side. There were no differences in governance performance for forest management practices, law enforcement and institutions. PANE had lowest scores for mean governance, forest management practices, institutions and participation.

4.2. The interrelation of different governance elements

The PCA showed that all governance elements loaded high on the first component, which already explained 55.2% of the variance (Fig. 3, Table 3). Bivariate correlations corroborate these findings: 7 out of 10 pairwise correlations between these five governance elements were statistically significant (correlation coefficients not depicted, p < 0.05). Additional components were characterized by single governance elements that loaded high on these. *Participation* had the strongest individual effect on the second component. The third component differentiated *tenure* against *institutions* and the fourth component was strongly determined by *law enforcement*. The fifth component differentiated (to a weaker extent) forest management practices against institutions (Table 3). However, the explanatory power of these latter components was low, as only the first component had an eigenvalue above 1.

The loadings on the first axis significantly correlated with mean governance (p < 0.05) (Fig. 4). In other words, governance arrangement patches with high mean governance were characterized by high loadings on the first component.

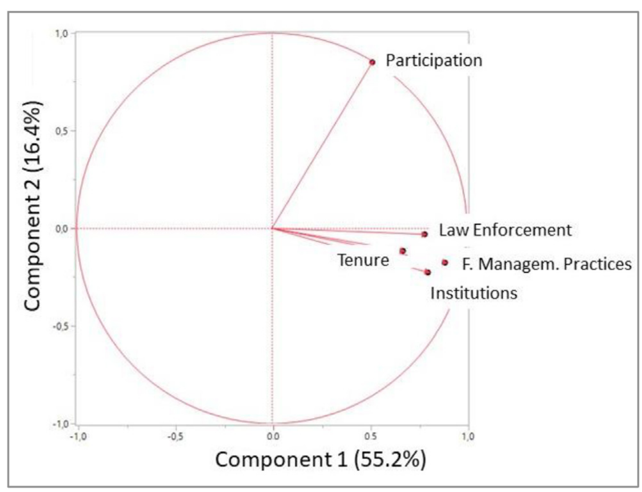

Fig. 3.. Biplot of a PCA for Likert scores of five governance elements assessed for 25 patches.

Table 2
Wilcoxon Test for governance differences between governance arrangements. Arrangements that do not share the same capital letters are significantly different (p < 0.05) as result of the Wilcoxon Test (Wlcx); N: number of patches; mean: mean governance. For PANE areas, only the mean is reported; they are excluded from the test due to low sample size of 2. SBosque/IndRes – pooled category of Socio Bosque and indigenous reserves.

Governance arrangement	N	**Mean governance**		Tenure		Forest Management Practices		Law Enforcement		Institutions		Participation	
		Wlcx	**mean**	Wlcx	mean	Wlcx	mean	Wlcx	mean	Wlcx	mean	Wlcx	mean
SBosque/IndRes	7	**A**	**3,6**	A	4.5	A	3.8	A	3.9	A	2.1	A	3.6
Communal	10	**A B**	**2,8**	B	3.3	A	3.5	A	3.6	A	2.2	B	1.8
Individual	6	**B**	**2,7**	B	3.0	A	3.4	A	3.0	A	1.8	B	1.9
PANE	2	**– –**	**2,4**	– –	3.2	– –	2.7	– –	3.1	– –	1.3	– –	1.7

Table 3
Loadings on the principal components (PC). Loadings larger/smaller than +/− 0.5 in bold. By definition, loadings of each variable can range between −1 and 1. High positive or negative loadings indicate strong explanatory power of the indicators for the respective component. Eigenvalues are given in brackets. An eigenvalue of 1.0 (2.0 or 3.0) indicates that the respective component explains as much variation as one (two or three) single variables.

	PC 1 (2.8)	**PC 2** (0.8)	**PC 3** (0.7)	**PC 4** (0.5)	**PC 5** (0.2)
Tenure	**0,67**	−0,11	**0,68**	0,26	0,11
Forest Management Practices	**0,89**	−0,18	−0,17	0,18	−0,34
LawEnf	**0,78**	−0,03	0,13	**−0,61**	−0,00
Institutions	**0,80**	−0,23	−0,46	0,12	0,28
Participation	**0,52**	**0,85**	−0,06	0,08	0,02

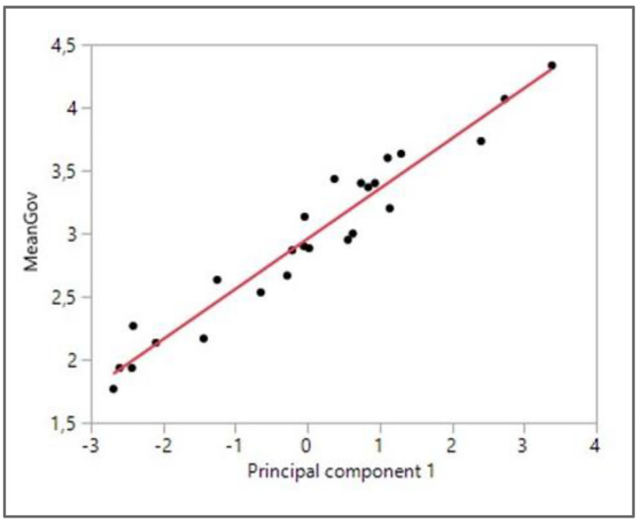

Fig. 4. Correlation between loadings on first principal component and mean governance for 25 governance arrangement patches (r^2 = 0.94, $p < 0.01$). Loadings on the first component are adjusted for the mean and standard deviation (SAS, 2017).

4.3. Bivariate correlations of potential deforestation drivers with deforestation

We calculated single bivariate correlations of infrastructure, socio-economic, land use and governance variables with deforestation (see Annex 2). Infrastructure variables did not correlate with deforestation. Among socio economic variables, the literacy rate and income from forests were highly significant. Land use cover variables were mostly related to deforestation. In addition, percentages of specific land use types correlated among themselves which was to be expected as land use percentages per patch always add up to 100% in a sense that high percentages of the land covered e.g. by forest automatically resulted in lower percentages covered by agriculture. Among governance elements, participation, law enforcement and tenure correlated negatively with deforestation. Also mean governance, which was based on all five governance elements correlated with deforestation.

4.4. Multiple linear regressions explaining deforestation

Multiple linear regression allows to analyze effects of multiple predictors (deforestation drivers) on a target variable (deforestation). Model a (Table 4, column a) excluded governance and had an r^2 of 0.34. In this model, percentage of households with electricity, literacy and the percentage of land covered by crops were significant explanatory variables. In model b (Table 4, column b) governance arrangements were added as explanatory variables which increased the r^2 to 0.47. Results show that deforestation was significantly higher on managed communal and individual lands as compared to the reference of Socio Bosque and indigenous reserves. Distance to markets was also significant in this model. In model c (Table 4, column c) mean governance was added as additional variable and significantly contributed to the explanation of deforestation. In this model, relative income from forests was negatively related to deforestation. In model d (Table 4, column d), we replaced mean governance by single governance elements. These explicit governance variables contributed more explanation to deforestation than mean governance as they increased the r^2 to 0.54. Specifically tenure and participation were highly significant. These two governance elements had also shown significant differences between individually and communally managed land on one side and protected areas on the other side (Table 2) and were at the same time most clearly differentiated from the remaining governance variables on the second and third component of the PCA (see Table 4). In model d, individual and communal arrangements turned insignificant. Participation and tenure as single selected governance elements thus overruled governance arrangements as explanatory variables. Law enforcement was significant in the multiple linear regression but had to be removed due to a high VIF above 5. VIFs for tenure and participation were moderately high but below 5 (4.6 and 3.4 respectively).

In general, governance either as selected elements or as overall mean had an effect on deforestation which is independent from other variables: when governance performance was high, deforestation was significantly lower. However, cropland percentage and electrification were significant in all four models and explained larger parts of the variation, showing that agricultural land use and intensification as well as infrastructure development are predominant proximate deforestation drivers in the analyzed landscapes.

5. Discussion

5.1. The interrelation of different governance elements

The main finding with regard to interrelations between single governance elements is that they all load positively and high on the first PCA axis, which already explains 55% of the variance of the governance elements (see Fig. 3 and Table 3). This finding is based on the fact that correlations between single governance elements were mostly significant. The different governance elements are obviously expressions of a same underlying process. Governance as observed in the field study is a process that is characterized by several governance elements which act conjointly and which are not antagonistic. A predominant importance of single elements as differentiated by the framework of the World Resource Institute could hardly be identified. The general governance trend can be expressed by mean governance (see Fig. 4). As the loadings on the first component of the PCA were closely related to mean governance, the elements with highest loadings on the first component can be interpreted as those most strongly determining

Table 4
Multilinear regression models explaining mean annual deforestation per patch in the years 2008–2016. a: model disregarding governance information; b: model in addition including categories of governance arrangements, c: model in addition including mean governance performance; d: model with single governance elements instead of mean governance.

	a	b	c	d
r2 corr	0.34	0.47	0.50	0.54
Prob>F	***	***	***	***
N	80	80	80	80
Infrastructure				
%electricity	(+)*	(+)***	(+)***	(+)**
km roads /ha				
km_to_market		(+)**	(+)***	(+)**
km_to_agrimarket	ns	ns	ns	(+)**
Land use				
Crops%	(+)***	(+)**	(+)**	(+)***
Socio economics				
%read_write	(+)***	(+)***	(+)***	ns
$wage/h				
%income_forests		ns	(-)**	(-)***
%income_agri				ns
Governance arrangement				
Communal		(+)**	(+)***	ns
Individual		(+)**	ns	ns
SBosque/ResIndig		reference	reference	reference
PANE		ns	ns	ns
Governance performance				
MeanGov			(-)**	
Participation				(-)***
Institutions				(+)*
LawEnforcement				
ForestManPract				ns
Tenure				(-)***

+/−: positive/negative estimator.
ns: not significant.
significance levels: * 0.1; ** 0.05; *** 0.01.
light grey cells: variable excluded during backward selection.
dark grey cells: variable not considered in the model.(%electricity: percentage households with electricity; km_to_market: km from community center to nearest general market; km_to_agrimarket: km from community center to nearest agricultural market; Crops%: percentage of patch classified as crop land; %read_write: percentage of population that can read/write; $wage/h: hourly rate for wage employment of an unskilled worker in US Dollars; %income_forests: mean percent of household income from forests; %income_agri: mean percent of household income from agriculture; SBosque/ResIndig: pooled category of Socio Bosque and indigenous reserves; PANE: state protection areas).

mean governance. But as four out of the five elements had loadings between 0.67 and 0.80 it is hard to claim a predominant role of one of them. The results confirm (Fischer et al., 2020) who applied the same methodology to 26 governance elements as derived from 28 reviewed studies and who did not find substantial negative loadings on the first component of a PCA as well. The homogeneous and harmonized data set from the field study shows this trend even more clearly as compared to the heterogeneous review data set. However, the global findings of Fischer et al. (2020) provide the basis for a generalization of our results.

Our findings have implications for the understanding of governance functioning. We cannot falsify the concept of governance, building on actors and structures and their interactions (Giessen & Buttoud, 2014) (see Fig. 1). We found indications that these governance components as quantified by five governance elements are equally important. At least for the extensive data set from tropical Ecuadorian forests we claim that none of the different components is more strongly determining overall governance.

In view of the large number of governance elements that have been described in different frameworks (Broekhoven et al., 2012; Davis et al., 2013), the results are encouraging for policy, applied development work and further research. The positive interrelation of governance elements suggests that work on one element may have positive effects on others and that governance elements behave synergistically. They are not antagonistic. As it is simply impossible to focus on all governance elements in development work, policy or research, it may be promising to select a few of them and concentrate work on these. The conceptual framework can be applied to make sure that actors, structures and interactions are considered in the selection of elements. Beyond the general positive loadings on the first components there are governance elements that differentiate governance on additional components depending on the local context. We recommend that such locally important elements, like participation and tenure in the case of our Ecuadorian data set, receive specific attention in the respective implementation.

5.2. Governance effects on deforestation

We confirm that governance affects deforestation (Kanninen et al., 2007; Korhonen-Kurki et al., 2014; Stickler et al., 2017). This leads to lower deforestation in case of higher governance scores. We specifically confirm and further elaborate on the results of Barbier and Tesfaw (2015) who also carried out a comparison of deforestation effects of different governance elements in addition to proximate drivers, however with a few structural governance variables only. We differentiate this effect for five governance elements and show that the effects are independent from proximate deforestation drivers and have an additional effect on reduced deforestation (Table 4). However, the significance level and the explanatory power for governance elements was lower as for the proximate drivers which is rather plausible as governance elements are understood as underlying causes (Geist & Lambin, 2002) (see Fig. 1) in comparison to direct deforestation drivers such as e.g. agricultural land use (Hosonuma et al., 2012; Ferrer Velasco et al., 2020). The results imply that in development work, policy and research a focus on governance elements alone is not sufficient. Governance needs to be tackled in addition to proximate causes of deforestation.

"Good governance" is based on a number of principals such as effectiveness, efficiency, transparency, accountability, legitimacy, lack of corruption, stability, empowerment, social justice, equity, environmental and social sustainability (Arts & Visseren-Hamakers, 2012; Secco et al., 2014; Ansell & Torfing, 2016). In this normative approach the principal question of "who has the right to define them" remains open (Secco et al., 2011). In practice, the above mentioned principals represent formal rules and norms as formulated in official policies, e.g. (UN, 2019). Our empirical results support the notion of a number of governance elements as indeed being "good" for low deforestation and thus justify the "good governance" approach related to this outcome. But the analytical approach which is based on empirical causalities can make it easier to negotiate and agree upon governance measures independently form implicit value statements, as informal values may substantially differ between e.g. indigenous and government stakeholders (Schweizer, 2017; Gupta & Koontz, 2019; Gustafsson & Scurrah, 2019).

In our analysis, the governance element of "institutions" comprised a mean of government, NGO and community institutions (see Annex 1). It hardly correlated with deforestation in a bivariate correlation (see Annex 2) but was positively related to deforestation in the multiple regression model (see Table 4). High institutional performance related to high deforestation (or vice versa) has hardly been reported so far. On the contrary, in a review for 28 governance studies (Fischer et al., 2020) well performing executive agencies were one of the most frequently mentioned governance components linked to reduced deforestation. A functioning into the opposite direction, i.e. well performing executive agencies linked to increasing deforestation, was only reported in two cases (Sendzimir et al., 2011; Bare et al., 2015), in which it was rather case specific and thus not comparable to our findings. In our study, institutions performance scored generally low with little variation. Statistical effects thus need to be interpreted with care. In addition it may be that we did not capture essential institutional factors, such as conflicts between formal and informal institutions. Nansikombi et al. (2020) point to the need to differentiate between customary and formal institutions, which would be a topic for further research in the Ecuadorian context.

5.3. Present land use and deforestation drivers as context for governance effects

Our results confirm for Ecuador that infrastructure, socio economic and land use variables have predominant effects on deforestation (Geist & Lambin, 2002; Barbier & Tesfaw, 2015). These variables need a specific discussion that relates their effects to governance and which also provides the basis for conclusions related to the specific local context.

Intensified agricultural land use, including ranching and livestock farming has been reported as a main deforestation driver in developing countries in general (Hosonuma et al., 2012) and specifically for Ecuador (Lerner et al., 2014; MAGAP, 2014). Castro et al. (2013) report that expansion of crops like cocoa, oil palm, rice, and cassava is the main deforestation driver along the Northwestern coast of Ecuador and in the provinces of Napo, Pastaza, and Orellana. Our findings are fully in line with these results. The development and implementation of improved land use systems, however, might be hampered by the specifically low governance scores for individual land ownership of settlers (see Table 3). Specifically performance of institutions and participation in decision making need to be improved as a basis for further developing land use systems that save or re-establish forests.

Road density is associated with economic-infrastructure development and it can be understood as an indicator of accessibility, which is related to a range of pressures on the natural environment and likely to affect forest cover negatively (Reed et al., 1996; Hawbaker et al., 2005). However in our study there was no significant relation to deforestation which might be explained by the in general low road density with little variation across the landscapes and the coarse data quality from the publicly available data sets. In fact, many gravel roads that we encountered in the field were missing in the data sets.

Among the socio-economic variables, literacy rate in the study landscapes related positively to deforestation. Direct positive links between literacy and deforestation would contradict numerous authors reporting that higher education is related to decreasing deforestation (Bhattarai & Hammig, 2004; Soares-Filho et al., 2004; Barsimantov & Navia Antezana, 2012; Baynes et al., 2016). In our study, settlers had highest literacy rates (not depicted, $p < 0.05$). Therefore, we interpret that it is not literacy itself which is related to increasing deforestation but potentially a more intensive and deforesting land use of the better-educated settlers. The effect of economic returns from forests on deforestation has been controversially discussed (Busch & Ferretti-Gallon, 2017). In our study, percentage of income from forests showed negative effects on deforestation. This shows that when forests are a source for income, deforestation might be lower which is in line with Bae et al. (2012) and Sendzimir et al. (2011) who report that income sources from forests could even foster reforestation. These findings mean that policy makers should take care that education is accompanied with sustainable management measures, such as certification or land use planning and that sustainable forest management is fostered as general safeguard for rural development projects.

Socio Bosque areas showed reduced deforestation as compared to communal and individually managed lands (see Table 4) and as well highest governance scores (see Table 2). Many authors report success of this incentive program (Loaiza et al., 2017; Jones & Lewis, 2015; Rosa da Conceição et al., 2015; Jones et al., 2017; Cuenca et al., 2018; Mohebalian & Aguilar, 2018), even though that the long-term viability and permanence depends on stable financing which was not always ensured in the past. Nepstad et al. (2021) point to the fact that the program is "currently largely dependent on the results-based payment agreements with the Green Climate Fund (GCF) and REDD Early Movers (REM). These contracts are relatively slow and bureaucratic in their implementation". Lessons from improved governance in these areas can stimulate to specifically work on tenure security and participation in adjacent areas as well. These governance elements scored specifically high in Socio Bosque areas. Mohebalian and Aguilar (2018) and Eguiguren et al. (2019) have claimed that the mere presence of Socio Bosque areas has positive effects on neighboring areas where logging operations are carried out and interpret this as, among others, spillover of governance effects. However, in these studies it remains open if Socio Bosque contracts are rather concluded with communities that already have better governance or whether the existence of such contracts leads to improved governance. Nevertheless, in both cases these results would advocate to extend governance improving measures to other land use forms.

The two PANE areas considered in this study show high governance performance for the ecological reserve of *El Pambilar* and low scores for *Mache-Chindul*. The ecological reserve of *Mache-Chindul* was established and use restrictions were superimposed when already indigenous people were living there. This creates land use conflicts until today as expressed by qualitative statements, low governance scores and higher deforestation rates. *El Pambilar*, on the other side, was created to solve land use conflicts between a logging company and indigenous people. The use restrictions are respected until today, because the involved stakeholders participated in the process and their own interest in dispute resolution was taken into account. For *El Pambilar*, governance scores were considerably higher and deforestation is low. These findings support the need to include local communities in decision making in order to sustainably implement conservation areas (Stocks et al., 2007; Oestreicher et al., 2009; Shahabuddin & Rao, 2010). In the specific case of the two PANE areas in Ecuador, institutions' capacities and local participation need to be improved as these elements scored specifically low in both cases.

6. Conclusions

Improved governance is today seen as core to approaches aiming to reduce tropical deforestation. Our study provides first insights into interrelations and functioning of different forest governance elements in the field. Such analytical understanding is urgently needed in order to complement a normative "good governance" approach.

Governance elements such as e.g. tenure, law enforcement, participation, institutional performance act conjointly and into the same direction, they are expressions of a same underlying process that is highly correlated to overall mean governance. This has implications for an analytical understanding of forest governance, which, based on our findings, is characterized by a synchronous functioning of different governance elements. Forest governance can be described by a conceptual framework including actors, structures and their interactions. This framework is now supported by empirical evidence because the results show that these components are equally important and interact positively. Such functional understanding of forest governance can support an efficient implementation of governance measures. From the multitude of governance elements that are described in existing assessment frameworks, the locally relevant ones need to be identified. These are elements that score low in all or in a number of governance arrangements. At the same time the selected elements should consider actors, structures as well as their interactions. Stakeholders in the forest governance arena can then rely on the justified assumption that work on a few, however well selected, core elements will have positive effects on the wider governance settings.

Multiple regression analysis confirmed an effect of specific governance elements on reduced deforestation. In the case of Ecuador mostly tenure and participation had an effect on reduced deforestation, but this may vary depending on the local context. Further studies are needed to analyze which governance elements have effects on deforestation in a differing context. The quantification of governance effects on deforestation is important to specify "good governance" as an approach that is to date mainly based on a number of politically accepted principles. The difference to such a normative approach is that our analytical understanding is outcome oriented. Analytical governance rather highlights cause-effect chains related to a specific outcome of interest. A normative approach rather relies on value-oriented principles without revealing causalities. This may be problematic as informal values of local stakeholders can differ from official principles.

Proximate drivers like infrastructure development and pressure from agricultural land use as well as the socio - economic context had stronger deforestation effects as compared to governance which is seen as an underlying factor. Proximate drivers urgently need to be taken into account and a sectoral emphasis on governance measures alone will not yield the expected results. However, governance measures are needed to ensure success of work related to proximate drivers.

Based on our landscape data from deforestation hotspots in Ecuador there are a number of case specific conclusions. We confirm agricultural land use as prominent direct driver of deforestation. Improved agricultural techniques are needed to reduce the pressure on remaining forests. Land use planning is important in order to ensure that improved techniques will not result in increasing opportunity costs that again accelerate deforestation. Indigenous communities need alternative land use systems and income possibilities as they are in the process of adopting agricultural methods of the settlers. Income from forests can be an alternative, however it is unclear how long such forest based livelihoods are sustainable in view of still ongoing deforestation. We show that Socio Bosque is a functioning incentive based forest conservation program that rightly receives attention. The program can stimulate governance development in neighboring individually (settlers) and communally managed (indigenous) lands as well as in other countries striving to include PES (payment for ecosystem services) programs e.g. under REDD+. With increasing pressure on primary forests specifically to be expected for the Amazon region, it seems to be relevant to install conservation areas like Socio Bosque in time. Nevertheless long-term financing needs to be ensured as international supporting programs are slow and bureaucratic. Forest state conservation areas (PANE) were rated with lower governance quality. Institutional performance and participation of the local population were specifically seen as critical and need to be improved.

CRediT authorship contribution statement

Richard Fischer: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Writing - original draft. **Fabian Tamayo Cordero:** Data curation, Project administration. **Tatiana Ojeda Luna:** Data curation, Investigation, Writing - review & editing. **Rubén Ferrer**

Velasco: Data curation, Software, Visualization, Writing - review & editing. **Maria DeDecker:** Data curation. **Bolier Torres:** Funding acquisition, Project administration, Resources, Writing - review & editing. **Lukas Giessen:** Supervision. **Sven Günter:** Funding acquisition, Methodology, Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Annex 1

Governance elements with indicators.

Tenure security

- *Recognition*. Individual and communal rights-holders have their rights formally recognized and recorded.
- *Demarcation*. Individual and communal forest lands have boundaries demarcated and surveyed.
- *Gender equity*. Rights registered to individuals or households are registered in the names of women, either jointly or individually

Forest Management practices

<u>Administration of timber licenses (for individual and communal land)</u>

- *Procedural clarity*. Clear administrative procedures regulate the obtaining of licenses and permits.
- *Timeliness*. Licenses and permits can be obtained in a reasonable time and within the time prescribed
- *Implementation*. Licenses and permits are honored during harvesting and transport of forest products

<u>Protection and conservation (for indigenous reserves and SNAP)</u>

- Use restrictions. Stakeholders clearly understand the timeframe and what activities are allowed and not allowed within the protection or conservation area.
- Enforcement. Implementing agencies are aware and effectively coordinate to carry out their roles and responsibilities.
- Monitoring. Implementation is subject to regular monitoring of impacts and effectiveness.

<u>Implementation of payments for ecosystem services (for Socio Bosque)</u>

- Procedures. The procedures for establishing PES have been made clear to the stakeholders.
- Benefit sharing. The schemes for benefit sharing have been jointly decided, understood and acceptable to the stakeholders.
- Protection. The protection of the forests providing these ecosystem services has been put in place.

Law enforcement

- Apprehension. Violators are apprehended and brought to trial by concerned authorities.
- Compliance. Penalties are served or are paid in full in a timely manner.
- Transparency. Information about penalties and their state of compliance is publicly disclosed

Institutions

- Government capacities. Government agencies have adequate number of staff with up-to-date knowledge and skills, technology and equipment, and budget to perform its roles and duties.
- NGO capacities. NGOs have adequate number of staff with up-to-date knowledge and skills, technology and equipment, and budget to provide services.
- Local community capacities. Local communities have adequate number of staff with up-to-date knowledge and skills, technology and equipment, and budget to perform its roles and duties.

Participation in public policy making

- Awareness. Nongovernmental stakeholders are aware in a timely manner of policies to be developed, reviewed and revised that are relevant for land use in their community.
- Platforms. Platforms are provided for multistakeholder participation in policy making
- Transparency. The stakeholders are informed of the results of policy engagements

Annex 2

Bivariate correlations between explanatory variables and deforestation

Variable	Description	Pearson correlation coefficient	Error probability
Infrastructure			
electricity (%)	% households with electricity	0,17	
km roads/ha	km roads/ha	0,1	
km_to_market	km to nearest market	0,09	
km_to_agrimarket	km to nearest agricultural market	0,07	
Land use			
Agrofor (%)	% of patch area agroforestry	0,3	***
Crops (%)	% of patch area crops	0,49	***
Pastures (%)	% of patch area pastures	0,41	***
PrimForest (%)	% of patch area primary forests	-0,53	***
HarvestFoestr (%)	% of patch area harvested forests	-0,1	

(*continued on next page*)

(*continued*)

Variable	Description	Pearson correlation coefficient	Error probability
SuccessForest (%)	% of patch area succession forests	0,27	**
Socio economics			
read_write (%)	% of population that can read/ write	0,33	***
$wage/h	hourly rate for wage employment	0,22	*
income_forests (%)	% of household income from forests	-0,3	***
income_agri (%)	% of household income from agriculture	-0.06	
Governance			
Participation	participation	-0,36	***
Institutions	institutions	-0,02	
LawEnforcement	law enforcement	-0,26	**
ForestManPract	forest management practices	-0,08	
Tenure	tenure	-0,18	*
MeanGov	mean governance	-0,29	***

Table: Pearson correlation coefficients for single bivariate correlations with % annual deforestation 2008–16; with error probabilities; N = 80 patches. ***p < 0.01, **p < 0.05, *p < 0.1.

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