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ARTICLE

# Forest Management Assessment Using LASSO and the Critical List of Variables for Sustaining the Commons: Four Cases in the Monarch Reserve

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## ABSTRACT

In the Monarch Reserve, four cases were selected for exploratory analysis using the critical list of variables for sustaining the commons and LASSO regression to determine which of these are most influential in the successful maintenance of forest cover over a decade. Forest recovery from degraded to dense forest is found to be inversely related to resource size, consistent with theory. However, in four other categories of forest change, the size of the resource is less influential, though it is still a significant, variable with a positive relationship to forest cover change which is inconsistent with theory. The analysis also showed that less overlap, greater poverty and lower dependence on the resource are associated both with forest gain and with mitigation of forest loss, which is contrary to theory and most research. Also associated with poverty in the LASSO regression are homogeneity of identity and ease of enforcement of rules. These show a negative relation to transitions from non-forest to dense forest, with low coefficients. This is inconsistent with theory. Possible reasons for the divergence from theory are discussed in detail, as is the utility of this approach for assessment and monitoring.

***Keywords:*** Common Pool Resource Systems; Forest Management; LASSO Regression; Monarch Butterfly Biosphere Reserve; Ejidos; Indigenous Communities

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# 1. Introduction

The Monarch Butterfly Biosphere Reserve (MBBR) in Mexico is a protected forest area constituting the largest overwintering area for the Monarch butterfly (*Danaus plexippus*) [1]. The Monarch is a charismatic species and tri-national pollinator [2]. Dense forest is beneficial to the Monarch for a number of reasons including habitat, ecosystem services, food sources, and local climate. At an even broader scale, healthy forests are an important global resource providing a broad spectrum of terrestrial functions [3]. Forests have a direct influence on climate, they are instrumental in the carbon cycle, and provide important eco-services and are biodiversity hotspots [4], and often sites of important endemism, as in the case of the MBBR [2]. Land use change and related risk factors, which result from use by local populations, tend to reduce forest ecosystem resilience and recovery [3]. There are over 100 human settlements with territory in the MBBR, many of which have been there for well over 100 years [5].

As such, the MBBR is an interesting example of a community-based natural resource management (CBNRM) system in a protected area (PA), as a large percentage (80%) of the PA is under some form of community or collective management [5, 6]. This means that the communities rely on the resource system. Forest management practices such as fuel wood collection, grazing and construction of roads reduce resilience of forest ecosystems making forests more susceptible to biome change, pathogens, diminished biodiversity, lower productivity and climate change [4]. For these reasons and because humans depend so heavily on the forest, it is important to enable efficient forest management. Thus, it is imperative to assess and monitor current management strategies as key in the mitigation of current and future crises.

In particular, it is important to determine what factors led to success in forest cover maintenance by examining the areas where management has been successful in the face of current threats (e.g., logging, forest degradation, climate change). In the MBBR there has been a mixed history of conflict and compatibility between regulatory and management practices, resulting in variation in management success in spite of the set of common rules established to protect the reserve area. However, in spite of the multiple interventions that have taken place in the Reserve over the last 40 years, there remain significant incoherencies and inconsistencies in management practices [2].

To evaluate and mitigate these issues, it is imperative to use consistent parameters and metrics that are well-tested and supported by theory. Such parameters are in the critical list of enabling variables. It is made up of 33 variables that are considered to be necessary for sustaining the commons [7]. These are divided into six categories, as shown in **Table 1**. This list is the result of decades of work by pioneering researchers: first presented by Ostrom (1990) as design principles (DPs), and then followed up by Wade (1994) [8], Baland & Plateau (1996) [9] and Agrawal (2003) [10]. Agrawal (2003) synthesized and added to the list in a publication on the topic. He lamented that "no studies of common pool resources develop their research design by explicitly taking into account the different variables critical to successful management as specified in the critical list of variables for sustaining the commons]," which was still true following a more recent publication [8]. This study seeks to incorporate the critical list in a detailed, preliminary analysis of forest management in four settlements in the MBBR.

In human-natural systems science, limited sample sizes with large variable sets pose a statistical analysis dilemma for researchers [7, 9, 10]. The critical list exemplifies this. The LASSO regression analysis is a relatively new approach presented by Tibshirani (1996) [11] as an alternative for analyzing over-fit data sets. This "sparse regression" technique [11] eliminates variables with insignificant influence on the dependent variable and can be used to model data with more variables than samples. It presents a potential to determine highly influential variables in large variable sets to inform immediate and/or long-term management strategy intervention. This study seeks to test the method using the applicable variables in the critical list as parameters.

**Table 1.** The full list of critical variables as adapted from Agrawal (2003).

| Variable Category | Variable |
|---|---|
| **1. Resource system characteristics** | Small size (RW) |
| | Well defined boundaries (RW, EO) |
| | Low levels of mobility (AA) |
| | Possibilities of storage from benefits from the resource (AA) |
| | Predictability (AA) |
| **2. Group Characteristics** | Small size (RW, B&P) |
| | Well defined boundaries (RW, EO) |
| | Shared norms (B&P) |
| | Past successful experiences—social capital (RW, B&P) |
| | Appropriate leadership—young, familiar with changing external env, connected to local traditional elite (B&P) |
| | Interdependence among group members (RW, B&P) |
| | Heterogeneity of endowments, homogeneity of identities interests (B&P) |
| | Low levels of poverty (AA) |
| **3. Relationship between resource characteristics and group characteristics** | Overlap between user-group residential location and resource location (RW, B&P) |
| | High levels of dependence by group members on the resource system (RW) |
| | Fairness in allocation of benefits from common resources (B&P) |
| | Low levels of user demand (AA) |
| | Gradual change in levels of demand (AA) |
| **4. Institutional arrangements** | Rules are simple and easy to understand (B&P)<br>Locally devised access and management rules (RW, EO, B&P) |
| | Ease in enforcement of rules (RW, EO, B&P) |
| | Graduated sanctions (RW, EO) |
| | Availability of low-cost adjudication (EO) |
| | Accountability of monitors and other officials to users (EO, B&P) |
| **5. Relationship between resource system characteristics and institutional arrangements** | Match restrictions on harvest to regeneration of resource (RW, EO) |
| **6. External Environment** | Technology: Low cost exclusionary technology (RW) |
| | Technology: Time for adaptation to new technologies related to the commons (AA) |
| | Low levels of articulation with external markets (AA) |
| | Gradual change in articulation with external markets (AA) |
| | State: Central governments should not undermine local authority (RW, EO) |
| | State: Supportive external sanctioning institutions (B&P) |
| | Appropriate levels of external aid to compensate local users for conservation activities (B&P) |
| | Nested levels of appropriation, provision, enforcement, governance (EO) |

*Note: EO refers to Elinor Ostrom, RW refers to Robert Wade, B&P refers to Baland and Plateau, and AA refers to Arun Agrawal.

# 2. Materials and Methods

## 2.1. Study Area: Monarch Butterfly Biosphere Reserve

In 2007, the area was designated a Biosphere Reserve under the UNESCO program, and in 2008, it made the World Heritage list. Forest management and monitoring rules were established with the designation by presidential decree of the MBBR in 1986 of 16,100 ha of mostly commonly held land. These were revised when the boundaries were expanded in 2000 to 13,551 ha of core area and 42,707 ha of buffer zone. The designation of the protected area and the management rules that followed were initially informed by a preservationist mentality rather than a participatory conservation strategy. This led to resentment and resistance by the local people [8, 12]. At the same time, industrial logging, which was already present, was allowed to continue through government-issued permits and concessions for local and outside interests, resulting in enforcement issues and encouraging clandestine activity [13]. This policy conflicted greatly with the traditional local livelihood system and even with tourism in the area, as logging caused significant deforestation, particularly during the years 2001–2006 [14]. It should be mentioned that there has been a reduction in forest cover loss in most years since the Reserve was established in 1986 and expanded in 2000 [5, 15, 16].

Multiple cases were chosen for preliminary comparison. The case studies were selected to reflect the criteria outlined in Agrawal's (2003) compilation and additions to the critical list. Purposive sampling was used to select AN that have been apparently successful in managing their forest [17, 18] that were willing to participate, and safely accessible. For the purposes of this study, the term 'successful management' is defined as <0.03% forest cover loss in the buffer and core zones of the MBBR over time [1, 19]. Purposive sampling was also used to determine the Landsat images, which is discussed in the section on forest cover change mapping. Generally, this study was intended to be a test of utility of the integrative methods, mentioned above, as well as a means to add to the body of CPR and community based natural resource management (CBNRM) case studies. Specifically, the AN were all within a relatively small geographical protected area and have many similarities, meaning that the results, if not generalizable to the whole world, may be relevant for the rest of the area, and therefore important for management of the Biosphere Reserve. The results, with this proviso, will add to the base of scientific literature on community resource management, as has been requested by researchers in the field [7, 10]. Four agrarian nuclei (AN) that participated in this study are located in the municipality of Zitácuaro (19° 29′0″ N and 100°19′0″ W) with territory inside the MBBR.

Of the four cases, two Indigenous Communities (IC) and two ejidos were chosen based on Bonilla Moheno et al.'s (2013) findings that Indigenous communities (IC) manage their resources more efficiently than ejidos to see if there are any evident patterns at a small scale. They were also chosen because of their apparent success in maintaining forest cover over time despite not having a formal management plan (other than the general rules associated with their location in the reserve). The IC Carpinteros received a National Indigenous Forestry Merit Award from SEMARNAT in both 2012 and 2013 and has had dense forest cover change of less than 0.02% per year for more than a decade. Carpinteros also hosts a small butterfly overwintering site inside the core zone, although it is not currently open to the public. The IC Curungueo has the more significant part of its area outside the reserve, with its external borders adjacent to the main highway that runs between large urban centers (Zitácuaro and Cuidad Hidalgo). The land holdings of ejido San Juan Zitácuaro (SJZ) are mainly within the limited human-use buffer zone (designed to protect the inner core zone from the area outside the reserve). SJZ won a National Forestry Merit award in 2012 and provides water resources to other ANs and to nearby urban areas. The ejido Nicolas Romero has not received any awards for forest management but has articulated in various reforestation activities and has a relatively large forest area, which falls almost exclusively in the buffer zone. These AN were chosen because they are examples of settlements that have sustained their forest cover over time [19, 20], with a positive trend in forest cover change from 1993 to 2006, and 2006–2015 based on a rapid analysis of forest cover change [21].

## 2.2. Data on Forest Cover Change

ArcGIS and Google Earth Landsat imaging were used to gather data on the dependent variable, forest cover change. The method described in Mishkin and Navarrete-Pacheco (2021) [20] was used to assess change in each year, and this was then aggregated and compared between two periods (2006 to 2010 and 2010 to 2015). The wet season (June to August) was used because we could apply the assumption of full canopy cover. Three land cover conditions were considered: dense forest (1), degraded forest (2), and non-forest (3). Dense forest is defined as areas of forest cover with 90 to 100% canopy coverage. Degraded forest was defined as forest area with 75 to 60% canopy cover. Non-forest was forest area with less than 30% forest canopy cover. Six possible transitions were identified and measured over the decade 2006 to 2015 in each of the ANs (1 to 2: dense forest to degraded forest, which may be considered degradation; 1 to

3: dense forest to non-forest (which is deforestation); 2 to 1: degraded forest to dense forest (natural recuperation); 2 to 3: degraded forest to non-forest (deforestation); 3 to 1: non-forest to dense forest (natural regeneration or reforestation); 3 to 2: non-forest to degraded, (reforestation – reforested areas show up as degraded because they are not fully grown and have relatively low canopy cover).

### 2.3. Data on the Explanatory Variables

Physical and demographic data were gathered at the local level from AN authorities, and questionnaires were used to collect data from a sample of households. This information provided values for sets of indicators that were used to quantify each of the relevant variables in the critical list of variables (**Table 2**). General opinions and views of the community members on forest management were also solicited. Seven variables were dropped from the critical list, for reasons indicated in **Table 2**, leaving 26 independent variables to provide potential explanations for observed differences in forest land cover change between the four ANs. Data on all 26 variables was normalized (expressed as a percentage of a base value).

The variables were scored on a quantitative scale using the frequency of response to specific questions (for the case of data derived from household questionnaires, n = 50) and using relative measures in the case of demographic data (e.g., relative size). Although all the ANs had relatively low rates of forest cover change, there were considerable variations in the values of the independent variables.

### 2.4. Statistical Analysis

Given that we had more variables (26) than the number of samples (4 AN), we needed a method robust to overfitting. The "Least Absolute Shrinkage and Selection Operator" (LASSO) regression is a statistical technique designed to cope with cases with many more variables than than cases. LASSO avoids overfitting by imposing a "penalty constraint" that shrinks the regression coefficients towards or to zero. Variables with a regression coefficient equal to zero are not included in the final model, thus reducing the total number of variables. This results in a simpler model that is easier to interpret. The 'glmnet' package in R software was used to perform the LASSO regression, as specified by Hastie et al. (2015)[21]. The results from LASSO reported below are the regression coefficient and the R^2 value (termed deviance ratio in LASSO literature). Because the penalty constraint pushes the values towards zero, the coefficients for the individual variables are most informative in terms of directionality and size relative to the other coefficients in the same category.

## 3. Results

### 3.1. Operationalized Variables

The results are presented in two parts. The first gives the operationalized (normalized) values of the variables (**Table 3**), and the forest transition values (**Table 4**). Secondly the results from the LASSO regression are presented in **Table 3** and in detailed text.

### 3.2. Results of the LASSO Regression

Results of the regression modeling of each of the six forest cover change outcomes with the critical variables are shown in **Table 5**. They are discussed in greater detail below, in terms of forest loss and gain.

Transition 1 to 2: Dense to degraded forest

The three most significant variables relating to this transition together explain 38% (R^2: 0.3822) of the total variation in this transition variable between ANs. Overlap has the most influence on this transition, based on the coefficients. This variable, which is negatively related to the outcome variable, explains approximately 35% of the variation in outcomes across the four ANs. Since high scores on this variable imply greater overlap, the results are inconsistent with theory (greater proximity of the resource to the living areas leads to more loss of forest in the form of degradation). Adding in the Resource System Small Size and Fairness contributes only an extra 3%. The signs for Small Size and Fairness in the regression are also negative, so one can infer that larger forest area results in more degraded forest (consistent with theory). The Fairness variable however does not comply with theory, which posits the hypothesis that Fairness contributes to the chance of good forest management.

Transition 1 to 3: Dense forest to non-forest (deforestation)

**Table 2.** Variables from the critical list that were omitted in the analysis.

| Variables Omitted | Reason for Omission |
|---|---|
| Low levels of mobility | The mobility of the forest as a resource is not applicable. |
| Possibilities of storage from benefits from the resource | This was so consistent among samples that it would have resulted in statistical washout. |
| Predictability | This is difficult to measure for a forest and immaterial to the analysis. |
| Gradual change in levels of demand | This is not applicable as the forest material cannot be legally sold or traded. |
| Technology: Time for adaptation to new technologies related to the commons | This is inapplicable as there is no need to adapt to fences, nor are fences new technology. |
| Low levels of articulation with external markets | This is not applicable as the forest material cannot be legally sold or traded. |
| Gradual change in articulation with external markets | This is not applicable as the forest material cannot be legally sold or traded. |

Resource Dependence and Resource System Small Size are contributing the most to the explanation of the transition from dense forest to non-forest (1 to 3). Overlap contributes the least. This implies that as size increases, deforestation increases; as dependence on the resource system decreases, deforestation increases; and as overlap increases, deforestation decreases (all these variables show negative relations to the outcome, but as shown in **Table 5**, the values on the Small size and Overlap variables are already inverted). The size variable results are consistent with theory, since it is hypothesized that larger areas of resource are more difficult to manage and control than smaller ones. Overlap is consistent with theory in this case. Resource dependence is contrary to what theory suggests. High dependence on the resource should theoretically decrease deforestation. The reasons for this unexpected result will be elaborated on in the discussion section, below.

Transition 2 to 3: degraded forest to non-forest (deforestation)

The three variables that emerged as the best explicators of this transition are Resource Small Size (negative), Overlap (negative) and Dependence (positive), which together explain about 34% of the variation ($R^2$: 0.3394). Overlap is the most significant in this, and as with the transitions discussed above, this is contrary to theory: as overlap (proximity) increases, deforestation increases. Second, as Fairness increases, deforestation increases.

Transition 2 to 1: degraded to dense forest (natural recuperation)

For the transition degraded to dense forest (2 to 1), the regression equation explains 72.54% of the variance in the outcome variables ($R^2$: 0.7255). Resource Small Size (negative relation), Overlap (positive relation), and Fairness (positive relation to the outcome) are the contributing variables. Again, the size variable is consistent with theory. Overlap was not, as the positive coefficient indicates that the lower the overlap the greater the reforestation or recuperation of the forest. Fairness was also contrary to theory as this result shows that as fairness increases, recuperation decreases.

Transition 3 to 2: non-forest to degraded forest (natural regeneration or reforestation)

The three variables which together explain 66% of the variation in this transition are Dependence on the resource (negative), Resource Small Size (negative) and Overlap (negative). Dependence is the best explanatory variable for this outcome, which could represent either reforestation or natural recuperation on abandoned lands. The coefficients indicate that as dependence on the resource system decreases, reforestation increases, which is in line with the theory. This is followed by Resource Small Size and Overlap.

Transition 3 to 1: Non-forest to dense forest (natural regeneration or reforestation)

This transition includes both reforestation and natural regeneration of forests as a result of abandonment of agriculture. The three most powerful variables together explain 32% of the variation between the ANs ($R^2$: 0.3147). Poverty (positively related) has the greatest influence on this transition (0.0300 $R^2$): as it increases, reforestation increases. This goes against theory; the critical list hypothe-

**Table 3.** Normalized values for the explanatory/independent variables used in the analysis.

| Variable | Ca | SFC | SJZ | NR | High Score Indicates | Hypothesized Relationship with Forest Cover Loss |
|---|---|---|---|---|---|---|
| **1. Resource system characteristics** | | | | | | |
| Small size | 85 | 59 | 63 | 83 | Smaller resource size | Negative |
| Well defined boundaries | 90 | 88 | 90 | 85 | Better defined boundaries | Negative |
| **2. Group Characteristics** | | | | | | |
| Small size | 88 | 63 | 81 | 68 | Smaller group size (population) | Negative |
| Well defined boundaries | 80 | 75 | 70 | 65 | Better defined boundaries | Negative |
| Shared norms | 82 | 82 | 89 | 81 | Greater level of shared norms | Negative |
| Past successful experiences | 90 | 90 | 92 | 75 | More past successful experiences | Negative |
| Appropriate leadership | 69 | 64 | 80 | 25 | Higher levels of belief in appropriateness of leader | Negative |
| Interdependence of group members | 94 | 84 | 97 | 82 | High interdependence of group members | Negative |
| Shared identity (HEHII) | 94 | 80 | 90 | 55 | Higher levels of shared identity | Negative |
| Low levels of poverty | 80 | 82 | 72 | 78 | Higher levels of poverty | Positive |
| **3. Extent of human pressure on the resource** | | | | | | |
| Low overlap between users and resource | 80 | 60 | 90 | 85 | Higher overlaps (resource is closer to residential area) | Positive |
| High dependence on the resource | 96 | 75 | 90 | 80 | Higher levels of dependence on forest | Negative |
| Fairness in allocation of benefits | 89 | 89 | 90 | 52 | Higher levels of fairness | Negative |
| Low levels of demand for forest products | 1 | 1 | 10 | 14 | Lower levels of demand | |
| **4. Institutional arrangements** | | | | | | |
| Rules are simple and easy to understand | 99 | 89 | 99 | 75 | Rules are easier to understand | Negative |
| Ease in enforcement of rules | 85 | 74 | 32 | 32 | Higher levels of ease in the enforcement of rules | Negative |
| Existence of Graduated sanctions | 79 | 79 | 89 | 89 | Greater presence of graduated sanctions | Negative |
| Availability of low-cost adjudication | 96 | 96 | 83 | 83 | Greater availability of low-cost adjudication | Negative |
| Accountability of monitors and other authorities to users | 92 | 83 | 92 | 73 | Greater accountability of monitors to users | Negative |
| **5. Extent to which rules take into account ecosystem potential** | | | | | | |
| Match restrictions on harvest to regeneration of resource | 95 | 90 | 95 | 90 | Higher levels of matching of restrictions on regeneration | Negative |
| **6. External environment** | | | | | | |
| Presence of low-cost exclusionary technology | 90 | 90 | 90 | 60 | Low-cost exclusionary technology is present | Negative |

Note: Ca = Carpinteros; SFC = Curungueo; SJZ = San Juan Zitácuaro; NR = Nicolás Romero.

sizes that Poverty tends to have an inverse relationship with reforestation, although it must be said that a broad swathe of practicing foresters consider Poverty one of the root causes of deforestation. The other variables, Homogeneity of identity and Ease of enforcement of rules are both negatively related to rates of transition from non-forest to dense forest but with much lower coefficients.

### 3.3. Discussion

As can be seen from the overview in **Table 6**, three variables (Overlap, Resource system small size, and Resource dependence) are consistently associated with forest gains, and with positive values, which is in keeping with the theory underlying the critical list. At the same time, these same three variables are associated in a negative direction with loss of forest, which also follows the theory. Poverty, which in theory is associated with increased risk of deforestation, is interestingly not indicated as such in the findings of this research. Instead, it is positively related to increases in forest cover. On the other hand, Fairness (which is understood to be an important condition to ensure communities manage forests well) is positively related to forest loss— a counter-intuitive outcome which is addressed below.

The results of the LASSO regression were varied with regard to their agreement with theory. The first observation is that most of the variables included in the list do not appear to be relevant in any of the forest transitions observed. Instead, a small number of these variables showed up in the LASSO analysis. The strongest relationship found throughout the study was Resource small size and forest recovery from degraded to dense forest. This showed a relationship clearly consistent with CPR theory. In four other categories of forest change, Resource small size is a less influential

**Table 4.** Forest transition values in the four ANs.

| Map Class | Area in Ha 2006 | – | – | – | Area in Ha 2010 | – | – | – | Area in Ha 2015 | – | – | – |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Car** | **Cur** | **SJZ** | **NR** | **Car** | **Cur** | **SJZ** | **NR** | **Car** | **Cur** | **SJZ** | **NR** |
| **1. Dense Forest** | 520.61 | 359.6 | 521 | 470.1 | 554.09 | 360.1 | 554 | 480.6 | 573.06 | 341.7 | 573 | 515.1 |
| **2. Degraded** | 78.03 | 379.7 | 78 | 47.2 | 45.97 | 423.2 | 46 | 39.8 | 26.87 | 443.3 | 27 | 24.5 |
| **3. Non forest** | 253.60 | 1118.2 | 254 | 46.5 | 252.28 | 1128.2 | 252 | 43.6 | 252.17 | 1125.6 | 252 | 24.4 |

but still a significant variable with an inverse relationship to forest cover change (the smaller the resource size, the larger the relative forest cover change), which is inconsistent with theory. There are two ways to interpret this. One is that this research does not support the CPR theory, at least in a protected area. The other is that, as Busch and Ferretti-Gallon (2017) found, size is not a significant factor as the results of their meta-analysis showed no indication that Small size impacted forest cover, making variability in results feasible. Regarding Resource small size, which is a significant variable in all forest cover changes except the change from degraded forest to non-forest, there is an inverse relationship to forest cover change.

The LASSO analysis also showed that less Overlap, greater Poverty, lower Dependence on the resource and larger Resource system size were associated both with forest gain and with mitigation of forest loss. CPR theory and most research tells us the opposite [5–7]. The other variables associated with Poverty in the LASSO regression were Homogeneity of identity and Ease of enforcement of rules. These both showed a negative relation to rates of transition from non-forest to dense forest, although with low coefficients. This negative relationship for both is inconsistent with Busch and Ferretti-Gallon's (2017) meta-analysis, as well as theory. The trend could be explained by the low normalized percentages for that variable in all the ANs. As an interesting aside, Busch and Ferretti-Gallon also found a statistically significant relationship between Indigenous people and forest cover maintenance, which would be interesting to explore in future research.

The Poverty variable shows a positive relationship with the recuperation of forest (non-forest to dense forest). However, its explanatory power is not as strong as some of the other variables, which are significant regarding this forest cover change category. This relationship goes against conventional theory that hypothesizes that poverty has a negative effect on reforestation. Although, it must be said that there are now mixed results regarding the impact of poverty and deforestation [22]. While poverty is commonly associated with deforestation, they found that greater poverty was associated with lower deforestation (p. 16), and our findings tend to support this.

Loss in the form of change from dense forest to non-forest was linked to Fairness and Resource small size. Both findings are contrary to CPR theory [7, 22]. The Fairness variable also emerges with a relationship contrary to theory in that less fairness leads to the growth and recovery of the forest. Fairness appears to lead to an increase in loss and degradation. There are a few possible reasons for this. The first is that perception of fairness may relate to negative feelings about Rule enforcement, which may be the factor that is, in fact, having a positive effect on forest cover outcomes. This signals a need to look at fairness through a different lens. There is a possibility, also considered by Busch and Ferretti (2017), that the dynamic as regards fairness changes with protected area status, limited resources, and available social capital. One consistent complaint was the excessive length of time it took to get permission to access fallen or diseased trees and non-timber forest products associated with them. In many cases it took months or permission was never granted, in spite of the waste and hardship that resulted from the restriction in access. There was also dissatisfaction among community members with the management of conflicts by State and National management organizations like CONANP, SEMARNAT and the Federal Police, making rule enforcement and conflict management by AN governing bodies inconsistent and difficult. As a result, conflicts between ANs could go on for years, even decades. Ideally, more consistent and open dialogue would rectify these lapses or at the very least address them before they had any negative impact on managers and users.

This study gives further reinforcement to the idea that local managers' knowledge and experience are key in the efficiency and sustainability of management— particularly those resources that have a high level of dependence and varied ecosystem services. It is also supportive of the idea

**Table 5.** LASSO results for the independent and dependent variables. An asterisk denotes the variable with the greatest percentage of influence. ResSmallSize = resource system small size; DepRes = high dependence on the resource. The variable with the asterisk is the most influential variable of the group.

| Forest Cover Change Transition | Independent Variables with Significance in the Model | R^2 (Deviance Ratio) | Regression Coefficient |
|---|---|---|---|
| **Forest Loss** | | | |
| **Transition 1 to 2** | *Total of 3 variables* | **0.3822** | |
| | Overlap* | | −0.00988 |
| | Fairness | | 0.0009 |
| | ResSmSize | | −0.00057 |
| **Transition 1 to 3** | *Total of 3 variables* | **0.3876** | |
| | DepRes* | | −0.0172 |
| | ResSmSize | | −0.0108 |
| | Overlap | | −0.0081 |
| **Transition 2 to 3** | *Total of 3 variables* | **0.3394** | |
| | Overlap* | | −0.0086 |
| | Fairness | | 0.0018 |
| | ResSmSize | | −0.0005 |
| **Forest Gains** | | | |
| **Transition 2 to 1** | *Total of 3 variables* | **0.7255** | |
| | ResSmSize* | | 0.0955 |
| | Overlap | | 0.01008 |
| | Fairness | | −0.0067 |
| **Transition 3 to 2** | *Total of 3 variables* | **0.6629** | |
| | DepRes* | | −0.0632 |
| | ResSmSize | | −0.0247 |
| | Overlap | | −0.0030 |
| **Transition 3 to 1** | *Total of 3 variables* | **0.3147** | |
| | Poverty* | | 0.0310 |
| | EasyEnforce | | −0.0128 |
| | HEHII | | −0.0057 |

*Note: The asterisks identify the most influential variable for each of the groups.

that cooperation and dialogue between local and external actors is important to success, which will be discussed in this section.

The results provide an interesting snapshot of forest management, as well as insights into successful management in the MBBR. Looking at the impacts of different variables on gains versus losses in forest cover change is particularly useful, in itself, for informing policy and management strategy on a case-by-case basis. In seeing the difference in those that enable positive forest cover change versus negative, we can zero-in on specific focal points that influence management. While influencing internal policy can be a challenge, particularly in community-based natural resource management (CBNRM), it is not impossible from an external perspective. Providing reports with information like that provided in this study is a way to provide suggestions respectfully and an opening for productive dialogue.

A final point regarding emergent topics is that in all of the literature on resource management and management strategies, monitoring is a consistent recommendation. Ostrom (1990), discusses how monitoring ensures the efficacy of strategies over time. This has been strongly supported by the research since[9, 10, 22]. There are many changes to a system that can result in a need to modify strategy to ensure the goal of sustainable and equitable management that, without monitoring, would result in management failure. Monitoring

**Table 6.** Detailed breakdown of the LASSO results and forest cover change transitions, where the sign associated with the regression coefficient is indicated.

| Transition | Transition Category | R^2 | Most Influential Variable | Consistent with Theory? | Additional Variables | Consistent with Theory? |
|---|---|---|---|---|---|---|
| **loss of forest** | 1 to 2 (degradation) | 0.38 | Overlap (-) | No | Fairness (-) | Yes |
| | | | | | Res Small size (-) | No |
| | 1 to 3 (deforestation) | 0.39 | Small size resource (-) | No | Dependence (+) | No |
| | | | | | Overlap (-) | No |
| | 2 to 3 | 0.34 | Overlap (-) | No | Fairness (-) | Yes |
| | (deforestation) | | | | Res Small size (-) | Yes |
| **increases in forest** | 2 to 1 (natural recuperation or reforestation) | 0.73 | Small Size resource (+) | Yes | Overlap (+) | No |
| | | | | | Fairness (-) | No |
| | 3 to 1 (natural regeneration or reforestation) | 0.32 | Poverty (+) | No | Ease of enforcement of rules (-) | No |
| | | | | | Identity HEHII (-) | No |
| | 3 to 2 (Natural regeneration or reforestation) | 0.66 | Dependence (-) | Yes | Small size resource (-) | No |
| | | | | | Overlap (-) | Yes |

saves time and resources if properly conducted and helps to assure resiliency in the face of natural or human-induced disturbance or catastrophe to natural systems of common pool resource management. Though it is not currently part of this study, the approach outlined in this investigation can be useful in monitoring the AN that participated, and ultimately the entirety of the MBBR. It is the intention of the first author to pursue this.

In terms of relevance to recent research, the results of this study appear consistent with one of the assertions made by Baggio et al. (2016)[22] and others— that one variable cannot explain why some common pool resource (CPR) systems are successful, and some are not. Clusters of interconnected variables, however, do seem to influence the success of CPR systems, as shown in meta-analyses[23]. Busch and Ferretti-Gallon (2017)[24] provided a meta-analysis based primarily on keywords and econometric drivers specifically related to forest cover change but found it difficult to generalize given the diverse and multivariate nature of CPR studies and varying criteria for operationalizing the variables. In spite of some inconsistencies in operationalizing, they came to the conclusion that there were clusters of variables that influenced forest cover that varied across cases, which makes sense in complex systems. Among the four cases examined in this study, however, no strong patterns were found. The LASSO regression in the present study gives insight into which variables are most influential in each AN. LASSO lends further credibility to the critical list (beyond the original Design Principles (DPs) presented by Ostrom (1990) as a pertinent and preliminary diagnostic tool to assess CPR systems, as it showed the varying intensity of influence by various variables in the list that went beyond the DPs. Further, the critical list results in a basis for comparison with other CPR case studies as it provides the indicator context and analytical elements to satisfy the requirements expressed by CPR researchers[7, 10, 22, 23] and a descriptive comprehension of the system useful for inter-level dialogue and enhanced cooperation.

# 4. Conclusions

While common pool resource management can be complicated, the results provide support that it is not impossible to tease out elements that influence success and encourage those. This study shows that it is possible to analyze 25+ variables and compare quantitative and qualitative data to determine significant and directional impact, thus providing a compass as to where to focus future studies and interventions. The models can be updated in the future if used as a monitoring tool. As a whole, this approach has a comparable input requirement in terms of time and resources to other participatory approaches. It could also be easily integrated into central government institutional processes with regard to monitoring and assessment, with the double benefit of providing much-needed dialogue and interaction with the nested levels of governance and actors that are currently lacking, at least in the MBBR. It is urgent to have the means to react quickly to significant external pressures on the MBBR and other CPR systems. There is an urgent need for rapid management strategy modification due to current and looming global environmental crises, and those require this level of information to avoid wasteful trial and error. This kind of systematic and inclusive approach would be a positive and encompassing step towards more effective CPR management and policy with the potential for theoretical advancement through a more systematic set of parameters, metrics for analysis, and a means to mitigate the dilemma of variable saturation using shrinkage.

## Author Contributions

Conceptualization: M.M., M.S.; Methodology, M.M., M.S., E.P.V., J.A.N.P.; ArcGIS software: J.A.N.P.; Validation, M.M., M.S.; formal analysis, M.M..; Investigation, M.M.; resources, M.M.; data curation, M.M. and E.P.V.; writing—original draft preparation, M.M.; writing—review and editing, M.M., M.S. and E.P.V.; visualization, M.M.; supervision, M.S.; project administration, M.M.; funding acquisition, M.M. All authors have read and agreed to the published version of the manuscript.

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## Institutional Review Board Statement

Institutional Review Board did not require ethical approval as the study fell into the exemption category Exemption 2 - 45 CFR 46.104(d)(2). The study was conducted in accordance with the Declaration of Helsinki, and approved by CONACYT (557476, 26/08/2013).

## Informed Consent Statement

Informed consent was obtained from all participants involved in the study.

## Data Availability Statement

Data is available by request to the first author. All data is original and confidential; participants are protected.

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## Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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