Appendix: Estimation of Scarcity Factor

1. Introduction

The estimation of the scarcity factor implies the identification of an area similar to the project area, where there has been a much stronger and sustained effect of deforestation over time, which allows visualizing how the loss of forest progressively decreases the capacity of the deforestation agent to deforest the remaining forest.

Accordingly, this appendix develops the work of selecting a proxy area similar to the project area, which is located in the department of Madre de Dios and corresponds predominantly to an Amazonian lowland rainforest environment. This area selection will allow us to calculate the relative rates of forest loss, using official information from the Peruvian state, and finally to produce specific deforestation data related to the remaining area of forest present in each selected district.

Finally, a non-linear model will be adjusted under the function defined by the VM00006 methodology for the establishment of the scarcity factor, this adjustment will be evaluated and optimized based on goodness-of-fit statistics that will allow calculating the parameters to obtain a general scarcity factor.

2. Proxy area

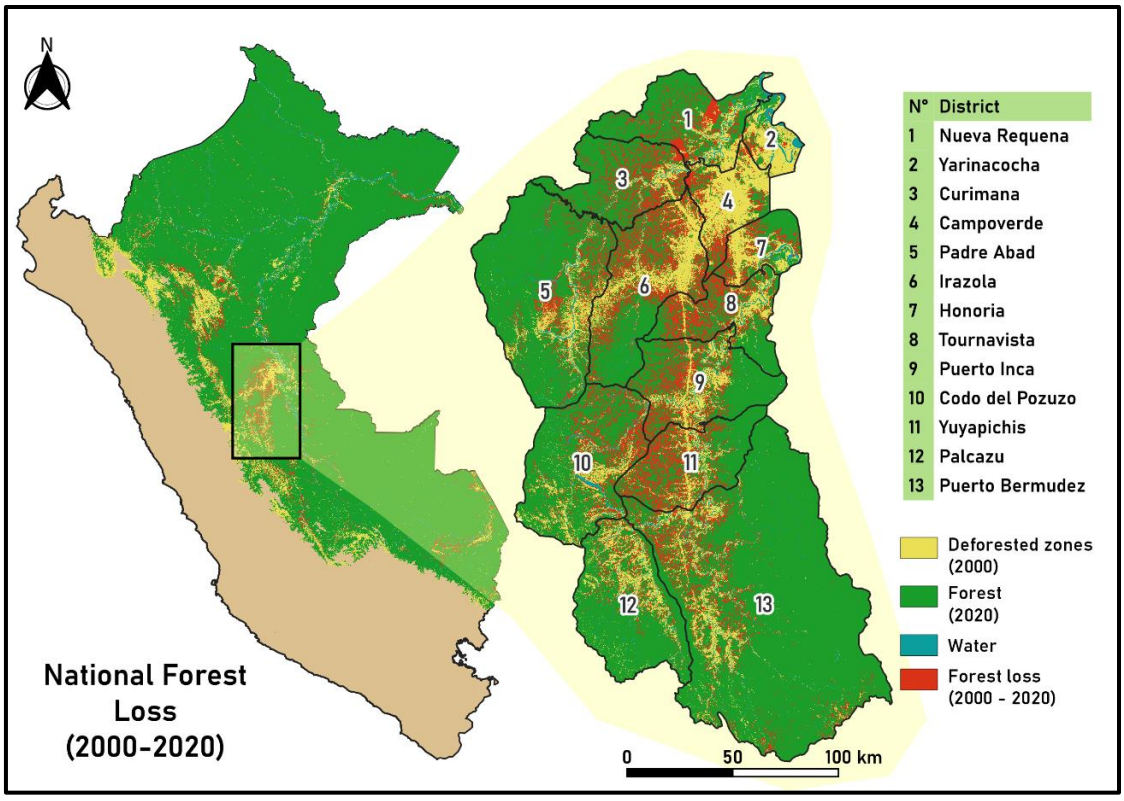

Figure 1. Forest loss in selected districts

In order to meet the requirements of the methodology, the temporal distribution of forest loss over the territory of Peru was evaluated for the period 2001 - 2020, using the data provided by the Ministry of Environment of Peru, under the application "GEOBOSQUES". It was observed that the main forest loss is concentrated in the

central zone of the lowland jungle of Peru, in the departments of Ucayali, Huánuco and Pasco. Thirteen districts were chosen (see Figure 1) with the highest accumulated loss rates, considering annualized losses and non-forest area for the year 2000.

Since the study area is located in the lowland rainforest of Madre de Dios, and in order to find landscape similarity, an altitude criterion was used to define similarity between the two areas to be compared. Areas higher than 500 m in altitude were excluded from the comparison.

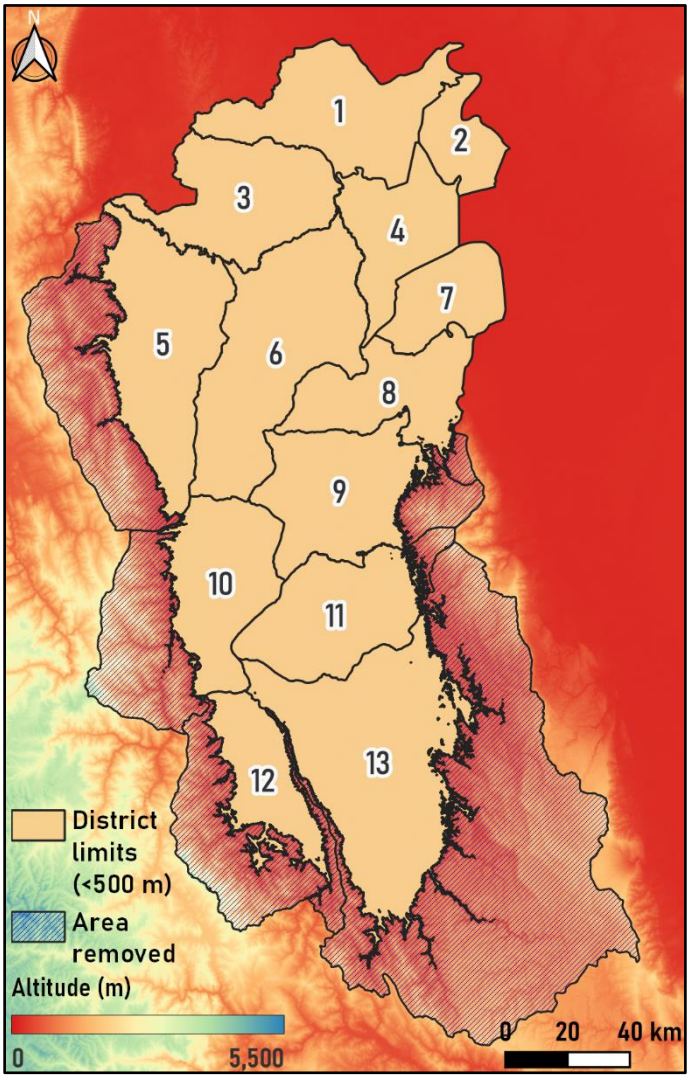

Figure 2. Removed areas

3. Forest area

For the purpose of calculating the areas of forest present in each district, as well as its remaining area and the percentage of this area as a function of the original forest cover size, the following equations were used:

$$\boldsymbol{Forest\ (2000) = Forest\ (2020) + Forest\ Loss (2000 - 2020)}$$

$$\boldsymbol{Forest + Non\ Forest = Forest\ (2000) + Non\ Forest\ (2000)}$$

$$\textbf{\textit{Remaining Forest}}\ \mathbf{2000}(\%) = \frac{\textbf{\textit{Forest}}\ (\mathbf{2000})}{\textbf{\textit{Forest + Non Forest}}}$$

$$\textbf{\textit{Remaining Forest}}\ \mathbf{2020}(\%) = \frac{\textbf{\textit{Forest}}\ (\mathbf{2020})}{\textbf{\textit{Forest + Non Forest}}}$$

Table 1 summarizes the total areas for each district and evaluates the percentages of forest cover for the years 2000 and 2020. It can be seen that most of the districts, despite the magnitude of annual forest losses, still retain a significant percentage of remaining forest area.

Table 1. Remaining Forest

N°	District	Non Forest (2000)	Forest (2020)	Water	Forest Loss (2000 - 2020)	Forest (2000)	Forest + Non Forest	% (2000)	% (2020)
1	Nueva Requena	27,092.34	132,155.46	8,539.11	38,205.00	170,360.46	197,452.80	86.28	66.93
2	Yarinacocha	38,372.94	12,180.87	10,122.03	5,454.18	17,635.05	56,007.99	31.49	21.75
3	Curimana	13,599.36	119,737.62	3,614.04	49,654.53	169,392.15	182,991.51	92.57	65.43
4	Campoverde	75,487.23	24,286.50	631.17	28,844.46	53,130.96	128,618.19	41.31	18.88
5	Padre Abad	36,061.38	158,831.46	10,435.05	46,375.29	205,206.75	241,268.13	85.05	65.83
6	Irazola	65,402.73	136,965.51	2,224.44	90,011.61	226,977.12	292,379.85	77.63	46.85
7	Honoria	27,770.13	40,775.67	3,904.02	22,403.79	63,179.46	90,949.59	69.47	44.83
8	Tournavista	21,899.79	72,079.20	3,681.90	50,049.27	122,128.47	144,028.26	84.79	50.05
9	Puerto Inca	37,596.60	90,735.30	5,776.56	57,058.11	147,793.41	185,390.01	79.72	48.94
10	Codo del Pozuzo	22,948.92	87,994.17	8,679.69	51,276.06	139,270.23	162,219.15	85.85	54.24
11	Yuyapichis	24,153.39	86,876.01	3,438.63	62,202.24	149,078.25	173,231.64	86.06	50.15
12	Palcazu	35,279.10	54,204.75	6,004.71	20,069.91	74,274.66	109,553.76	67.80	49.48
13	Puerto Bermudez	56,743.38	238,777.65	11,624.49	70,764.48	309,542.13	366,285.51	84.51	65.19

4. Deforestation rates

Table 2 develops the annual forest losses for each district, for the period 2001 - 2020.

Table 2. Annual deforestation rates for each disctrict

N°	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
1	412.92	284.49	397.44	154.53	759.51	182.07	279.09	435.06	816.39	685.26
2	275.76	221.22	322.29	144.36	857.07	526.14	186.12	180.00	999.00	187.92
3	885.60	693.90	926.10	773.10	962.28	565.56	1,063.62	1,272.60	2,853.72	2,313.00
4	1,230.03	928.26	698.31	744.84	3,528.09	1,019.52	1,151.19	1,867.77	2,756.07	1,937.70
5	1,170.18	1,324.35	2,073.96	749.25	1,778.04	1,125.63	1,279.17	2,183.85	3,144.51	2,460.06
6	2,789.64	2,575.17	4,068.99	2,857.32	6,146.37	3,552.84	2,617.20	4,639.23	6,022.98	5,917.68
7	967.32	1,079.46	492.75	609.48	1,922.31	837.72	579.78	934.11	1,954.35	1,037.25
8	915.57	1,268.82	854.46	1,023.75	4,063.68	1,602.36	1,133.19	2,772.63	4,168.44	2,710.35
9	1,654.11	1,670.49	1,495.26	1,258.65	5,265.09	964.53	1,214.10	3,066.21	3,763.17	2,264.31
10	1,014.93	1,537.47	3,470.94	897.57	2,821.23	1,011.33	1,804.59	2,771.46	2,938.50	3,151.71
11	2,419.02	1,758.60	2,485.89	1,812.51	4,896.63	1,650.33	2,424.51	3,534.66	5,839.29	3,392.37
12	719.46	1,336.14	1,178.46	730.71	1,254.69	755.01	835.65	665.55	1,084.23	1,109.97
13	2,058.30	1,420.11	1,431.99	2,500.47	5,311.62	2,213.46	1,332.54	1,693.26	4,492.35	4,711.14
N°	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**

1	787.77	3,025.08	6,593.94	2,468.34	2,696.58	3,347.73	3,262.41	2,905.29	4,721.40	3,989.70
2	319.41	115.56	112.68	152.37	174.78	208.80	234.63	37.62	112.50	85.95
3	3,045.69	2,804.76	6,238.08	4,487.85	4,068.36	3,257.10	3,616.92	2,756.25	3,539.25	3,530.79
4	2,515.32	1,393.29	1,380.24	1,431.45	1,388.70	1,225.89	1,536.93	608.22	658.62	844.02
5	3,073.23	1,672.20	4,724.19	3,117.15	2,761.29	2,509.38	2,082.15	2,223.63	3,129.03	3,794.04
6	5,757.48	4,063.68	5,946.03	5,907.06	6,153.66	4,688.82	4,229.64	3,249.99	4,369.86	4,457.97
7	1,628.37	1,404.09	1,471.95	1,177.02	1,298.34	1,209.24	1,912.95	559.08	770.49	557.73
8	3,075.66	3,863.25	3,447.36	3,672.27	3,411.18	2,227.86	3,015.00	2,090.70	2,269.71	2,463.03
9	2,851.92	3,906.81	3,748.05	4,744.53	4,360.23	2,889.18	2,492.91	2,893.86	3,357.09	3,197.61
10	2,430.99	2,775.15	3,689.73	4,600.71	3,528.18	2,502.36	2,289.87	2,623.95	2,499.75	2,915.64
11	3,975.48	4,645.89	3,484.26	5,522.31	3,172.59	2,107.08	2,237.04	2,473.29	1,908.99	2,461.50
12	831.69	908.37	1,136.52	1,453.05	1,405.44	1,005.57	859.95	730.44	833.67	1,235.34
13	3,717.90	5,663.16	4,533.84	6,056.82	4,160.25	3,720.87	3,842.19	3,771.72	3,510.81	4,621.68

Based on the specific deforestation rates, cumulative losses were calculated for each district, in order to observe the percentage of remaining cover for each year. Table 3 summarizes the relative values of remaining area, but transforms the data into a relativization by loss (in a range from 0 to 1), i.e., lower numbers indicate a smaller area of forest lost, while higher numbers (close to 1) indicate a greater loss of forest, close to the total elimination of the remaining forest area.

To relativize the data, we used the information of the variable "Forest + non-Forest", which represents the original forest cover of the district. Thus, the highest values are observed in districts 2 (Yarinacocha) and 4 (Campoverde), with a relative total forest loss of 78% and 81%, respectively. In other words, in both districts there is a remaining forest of 22% and 19%, compared to the original forest ("Forest + non-Forest"). These values represent the independent variable of the scarcity factor model.

Table 3. Relative area of lost forest cover

N°	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
1	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.16
2	**0.69**	**0.69**	**0.70**	**0.70**	**0.72**	**0.73**	**0.73**	**0.73**	**0.75**	**0.75**
3	0.08	0.08	0.09	0.09	0.10	0.10	0.11	0.11	0.13	0.14
4	**0.60**	**0.60**	**0.61**	**0.61**	**0.64**	**0.65**	**0.66**	**0.67**	**0.70**	**0.71**
5	0.15	0.16	0.17	0.17	0.18	0.18	0.19	0.20	0.21	0.22
6	0.23	0.24	0.26	0.27	0.29	0.30	0.31	0.32	0.34	0.36
7	0.32	0.33	0.33	0.34	0.36	0.37	0.38	0.39	0.41	0.42
8	0.16	0.17	0.17	0.18	0.21	0.22	0.23	0.25	0.28	0.29
9	0.21	0.22	0.23	0.24	0.26	0.27	0.28	0.29	0.31	0.32
10	0.15	0.16	0.18	0.18	0.20	0.21	0.22	0.24	0.25	0.27
11	0.15	0.16	0.18	0.19	0.22	0.23	0.24	0.26	0.29	0.31
12	0.33	0.34	0.35	0.36	0.37	0.38	0.38	0.39	0.40	0.41
13	0.16	0.16	0.17	0.18	0.19	0.20	0.20	0.20	0.22	0.23
N°	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
1	0.16	0.18	0.21	0.22	0.24	0.26	0.27	0.29	0.31	0.33
2	**0.76**	**0.76**	**0.76**	**0.77**	**0.77**	**0.77**	**0.78**	**0.78**	**0.78**	**0.78**
3	0.16	0.17	0.21	0.23	0.25	0.27	0.29	0.31	0.33	0.35
4	**0.73**	**0.74**	**0.75**	**0.76**	**0.77**	**0.78**	**0.79**	**0.80**	**0.80**	**0.81**
5	0.23	0.24	0.26	0.27	0.28	0.30	0.30	0.31	0.33	0.34
6	0.38	0.40	0.42	0.44	0.46	0.48	0.49	0.50	0.52	0.53
7	0.44	0.45	0.47	0.48	0.50	0.51	0.53	0.54	0.55	0.55
8	0.32	0.34	0.37	0.39	0.42	0.43	0.45	0.47	0.48	0.50
9	0.34	0.36	0.38	0.41	0.43	0.45	0.46	0.48	0.49	0.51
10	0.29	0.31	0.33	0.36	0.38	0.39	0.41	0.42	0.44	0.46

11	0.34	0.36	0.38	0.42	0.43	0.45	0.46	0.47	0.48	0.50
12	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.49	0.51
13	0.24	0.25	0.27	0.28	0.29	0.31	0.32	0.33	0.34	0.35

In order to find the relative deforestation rates, it was necessary to find a point of comparison. To standardize the criterion, the first rate of 2001 was used to compare with subsequent rates. However, since the tendency of these rates is to increase, mainly in areas where the remaining area is greater than 50% of the original coverage, the relativization generated values greater than 1. To solve this, all values greater than 1 were transformed as 1, since this evaluation seeks to indicate a value of decrease in deforestation rates, and an increase in these does not promote more information to the model to be generated.

On the other hand, in the two districts where the relative rate of forest loss exceeds 60%, the maximum deforestation rate for the period described was used, since there is no clear and continuous trend of decrease. With this modification, a representation of the decrease in the deforestation rate is more clearly observed, thus focusing on meeting the objectives that the scarcity model represents.

Table 4. Initial comparison deforestation rates

N°	Rate (ha)	Description
1	412.92	Forest loss rate 2001
2	999.00	Maximum rate value
3	885.60	Forest loss rate 2001
4	3,528.09	Maximum rate value
5	1,170.18	Forest loss rate 2001
6	2,789.64	Forest loss rate 2001
7	967.32	Forest loss rate 2001
8	915.57	Forest loss rate 2001
9	1,654.11	Forest loss rate 2001
10	1,014.93	Forest loss rate 2001
11	2,419.02	Forest loss rate 2001
12	719.46	Forest loss rate 2001
13	2058.30	Forest loss rate 2001

Table 5. Relative deforestation rates

N°	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
1	1.00	0.69	0.96	0.37	1.00	0.44	0.68	1.00	1.00	1.00
2	0.28	0.22	0.32	0.14	0.86	0.53	0.19	0.18	1.00	0.19
3	1.00	0.78	1.00	0.87	1.00	0.64	1.00	1.00	1.00	1.00
4	0.35	0.26	0.20	0.21	1.00	0.29	0.33	0.53	0.78	0.55
5	1.00	1.00	1.00	0.64	1.00	0.96	1.00	1.00	1.00	1.00
6	1.00	0.92	1.00	1.00	1.00	1.00	0.94	1.00	1.00	1.00
7	1.00	1.00	0.51	0.63	1.00	0.87	0.60	0.97	1.00	1.00
8	1.00	1.00	0.93	1.00	1.00	1.00	1.00	1.00	1.00	1.00
9	1.00	1.00	0.90	0.76	1.00	0.58	0.73	1.00	1.00	1.00
10	1.00	1.00	1.00	0.88	1.00	1.00	1.00	1.00	1.00	1.00
11	1.00	0.73	1.00	0.75	1.00	0.68	1.00	1.00	1.00	1.00
12	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.93	1.00	1.00
13	1.00	0.69	0.70	1.00	1.00	1.00	0.65	0.82	1.00	1.00
N°	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

2	0.32	0.12	0.11	0.15	0.17	0.21	0.23	0.04	0.11	0.09
3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
4	0.71	0.39	0.39	0.41	0.39	0.35	0.44	0.17	0.19	0.24
5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.58	0.80	0.58
8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
11	1.00	1.00	1.00	1.00	1.00	0.87	0.92	1.00	0.79	1.00
12	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
13	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

5. Goodness of Fit

The model was based on the function described in the Equation 40 of VM0006 v.2.2 methodology.

$$Scarcity\ factor = f(X) = \frac{1}{1 + e^{a(b-X)}}$$

Donde:

f (X): Scarcity factor
e: Base of the natural logarithm (approx. 2.7128).
a: Constant SC1, steepness of the decrease in deforestation rate.
b: Constant SC2, relative deforested area at which the deforestation rate will be 50% of the initial deforestation rate.
X: Proportion of initial forest area that is deforested

To determine the value of the constants a and b (SC1 and SC2, respectively), it is necessary to fit a non-linear model, using the two previously calculated variables, as independent variable the relative loss of remaining forest, and as dependent variable, the relative rate of deforestation. This adjustment was carried out in the MATLAB v.2022a environment, using the "Curve Fitting Tool" application. Three models were established based on the progressive elimination of outliers.

5.1. Model 1

The first model involved the use of all the data for an exploratory analysis to observe how the data are distributed.

Figure 3 shows an adjusted coefficient of determination (R^2) of 0.6791, which indicates a moderate fit to the model; however, there are many scattered points that generate noise in the distribution of points and cause considerable influence, this can be seen in the residual analysis (Figure 5), where in the section from 0.1 to 0.4 of the independent variable, there are outliers that modify the behavior, suggesting that a subsequent adjustment should be made to eliminate these values.

Results

General model:

f(x) = 1/(1+2.71828^(a*b-a*x))

Coefficients (with 95% confidence bounds):

a = -11.62 (-13.48, -9.754)

b = 0.6769 (0.6597, 0.694)

Goodness of fit:

SSE: 5.731

R-square: 0.6803

Adjusted R-square: 0.6791

RMSE: 0.149

Figure 3. Model 1 results

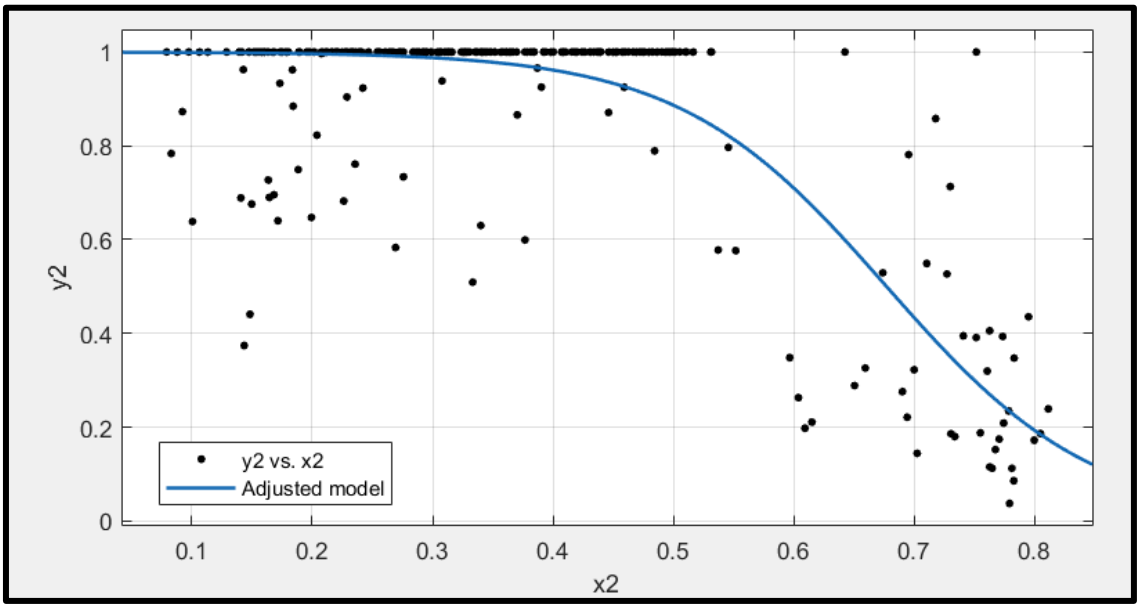

Figure 4. Adjusted model 1 with observation points

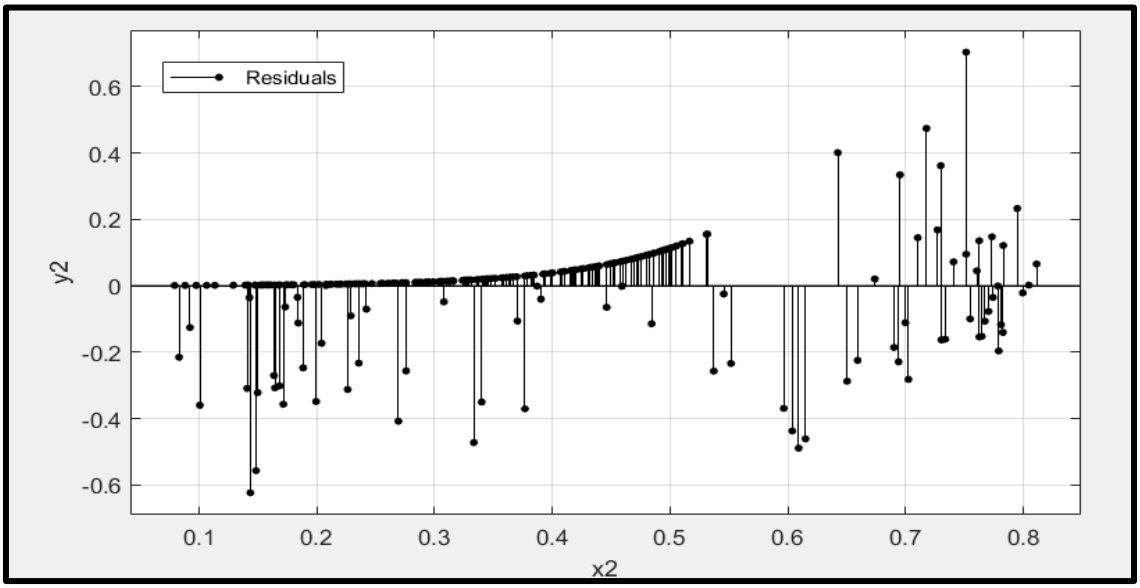

Figure 5. Model 1 residual distribution

5.2. Model 2

In model 2, points where the relative rate of deforestation decreased by more than 10% were eliminated for those points where the relative rate of forest loss did not exceed 50%, and points where the relative rate was greater than 0.6 were eliminated for those points where the relative rate of forest loss exceeded 60%.

Thus, an adjusted coefficient of determination (R^2) of 0.8928 was obtained, which indicates a higher model fit than the previous model. In this case, Figure 8 shows the residuals, where greater variability is observed in the last points.

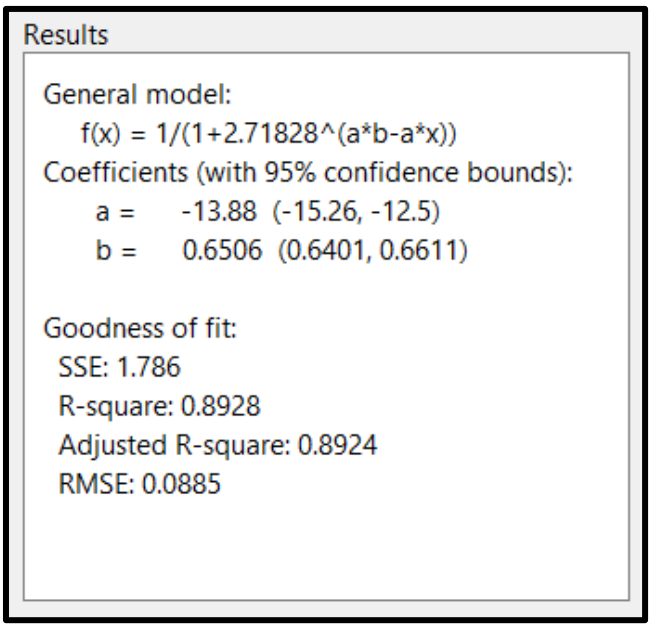

Figure 6. Model 2 results

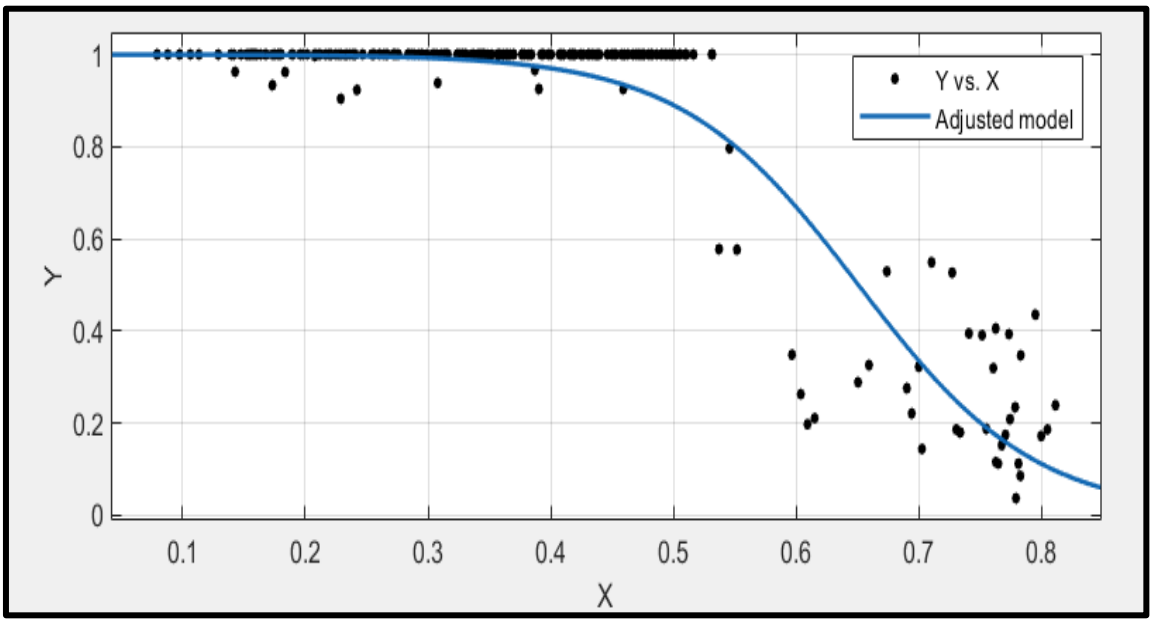

Figure 7. Adjusted model 2 with observation points

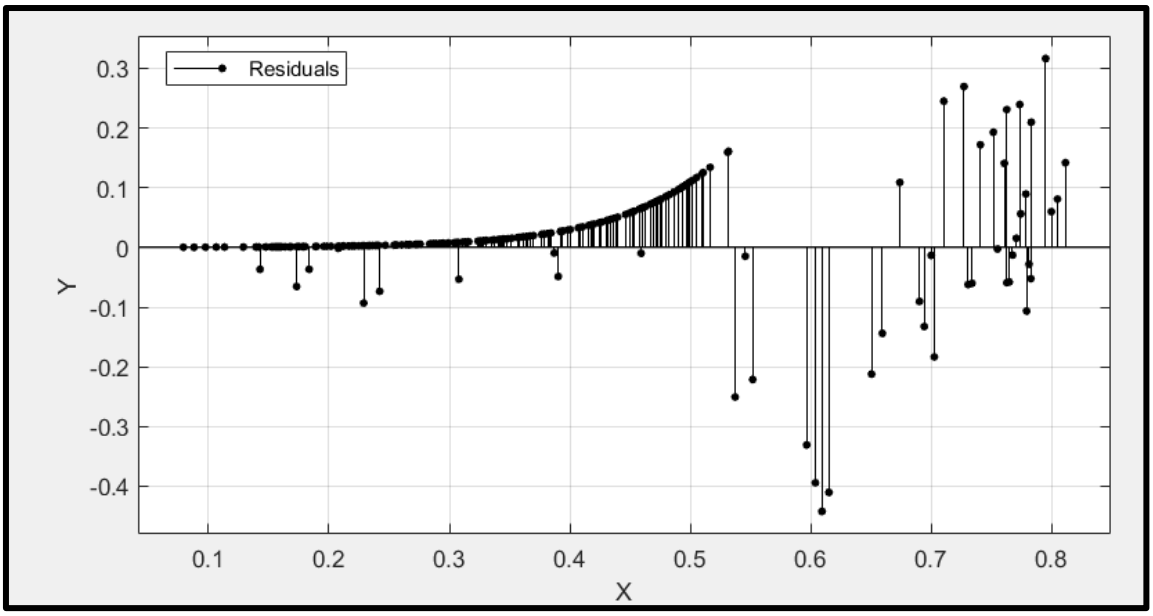

Figure 8. Model 2 residual distribution

5.3. Model 3

The last model uses the basis of the previous model and eliminates the values whose residuals exceed 0.3 units of the dependent variable. The points that were eliminated are shown in red (Figures 10 and 11).

This model obtains the best fit, with an adjusted coefficient of determination (R^2) of 0.9355.

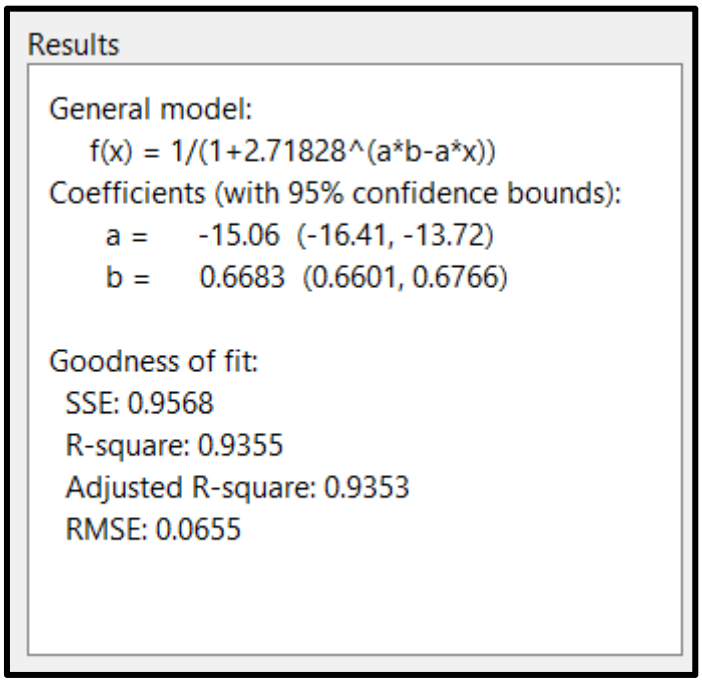

Figure 9. Model 3 results

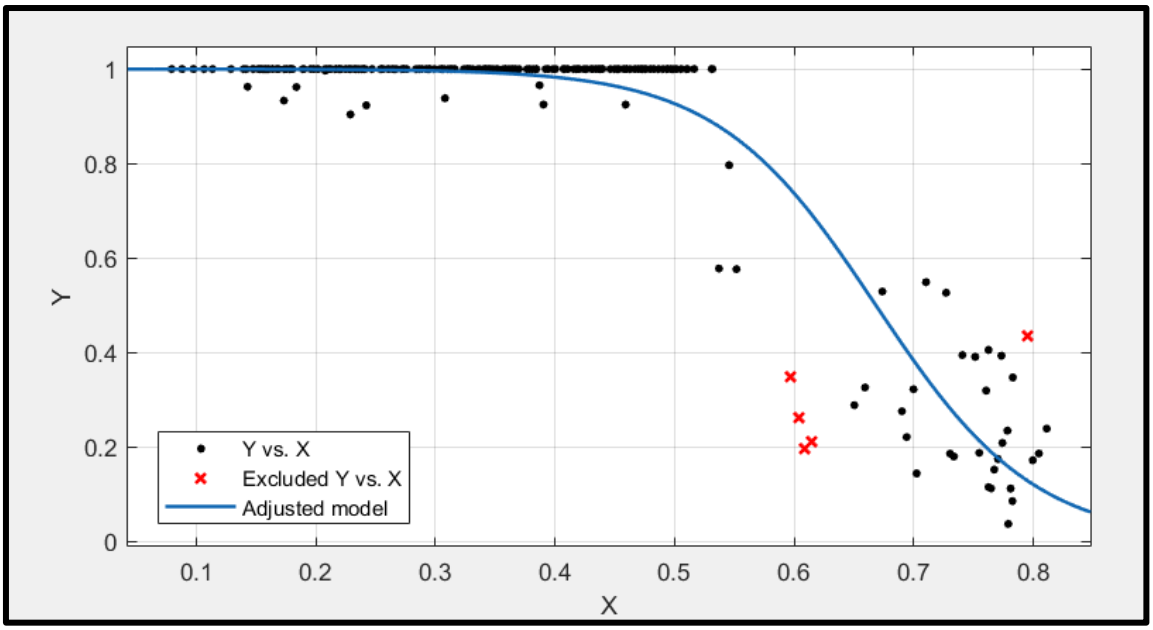

Figure 10. Adjusted model 3 with observation points

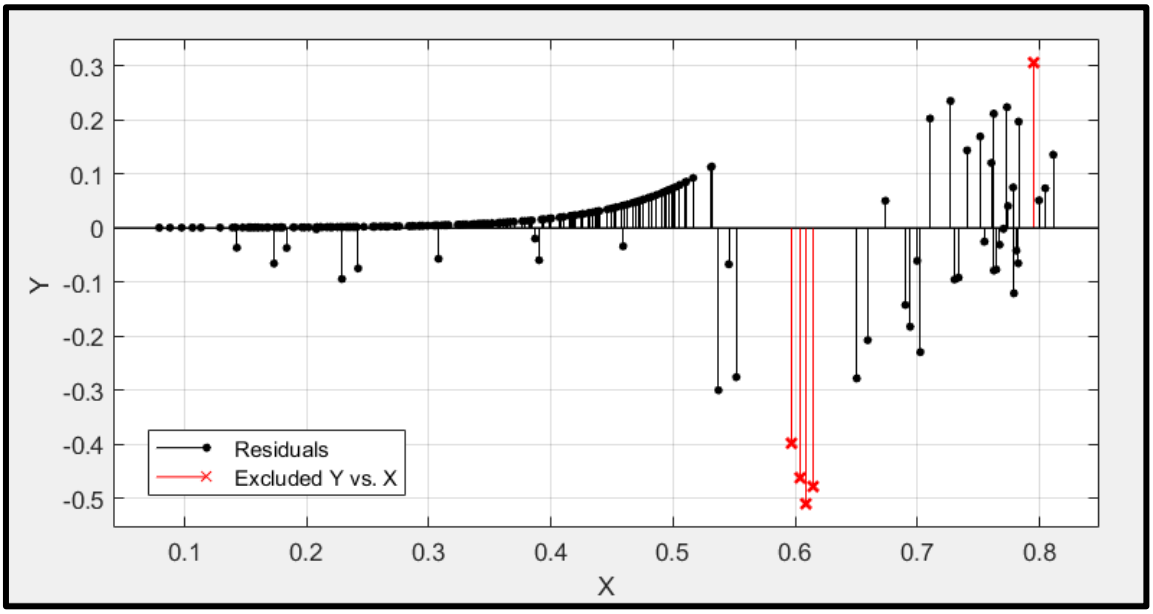

Figure 11. Model 3 residual distribution

5.4. Summary of models

Table 6 summarizes the fit metrics of each model evaluated, in all cases, model 3 obtains the best fit values, lower SSE (sum of square of residuals) value, where a value close to zero implies that the model has a lower random error component, and lower overall RMSE (standard error of the regression), which also implies a better fit.

Table 6. Summary of statistics

Model	a	b	SSE	RMSE	R^2_{ADJ}
Model 1	-11.62 (-13.48, -9.754)	0.6769 (0.6597, 0.6940)	5.731	0.149	0.6791
Model 2	-13.88 (-15.26, -12.5)	0.6506 (0.6401, 0.661)	1.786	0.0885	0.8924
Model 3	-15.06 (-16.41, -13.72)	0.6683 (0.6601, 0.6766)	0.9568	0.0655	0.9353

*** In parentheses the confidence interval of the coefficients, at 95%.**

6. Conclusions

Model 3 was selected, meaning that the values of the constants SC1 and SC2 are -15.06 and 0.6683, respectively; this implies that, at 66.83% loss of remaining forest, the relative rate of deforestation is reduced to half the original rate.