
Supplementary information

Strategic planning to mitigate mining impacts on protected areas in the Brazilian Amazon

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Strategic planning to mitigate mining impacts on protected areas in the Brazilian Amazon

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The supplementary material content:

- (1) Support documents consulted
- (2) Study region
- (3) Road design information
- (4) Deforestation surrounding roads in areas with high biological importance
- (5) Scenarios parameters
- (6) Land use and cover database corrections
- (7) Weights of Evidence used for the model calibration
- (8) Validation curves of calibrated and null models

1. Support documents consulted

Documents	Source	Description of future projects in the region
Jari Integrated Environmental Assessment [Avaliação Ambiental Integrada do Jari]	Empresa de Pesquisas Energéticas (http://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/avaliacao-ambiental-integrada-aa)	Transmission line in the development scenario of 2030 following the roads design.
MacroZEE Pará	Secretaria de Meio Ambiente e Sustentabilidade – Governo do Pará (https://www.semas.pa.gov.br/diretorias/planejamento-ambiental/zee/)	Area with low human pressure and protected by full protection and sustainable use PAs
Decenal Energy Plan [Plano Decenal de Energia]	Empresa de Pesquisas Energéticas (http://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/plano-decenal-de-expansao-de-energia-pde)	2029 – no relevant proposals for the region 2027 – no relevant proposals for the region 2026 – implementation of power station and transmission line from Laranjal do Jari to Jurupari
Paru Management Plan [Plano de Manejo da Flota do Paru]	Imazon (https://imazon.org.br/cartilha-do-plano-de-manejo-da-flota-do-paru/)	Zones with low – conservation and forest management -or moderate intervention – only extractives activities of non-timber products and mineral research

Table S 1. Documents consulted about planned projects in the region

2. Study region

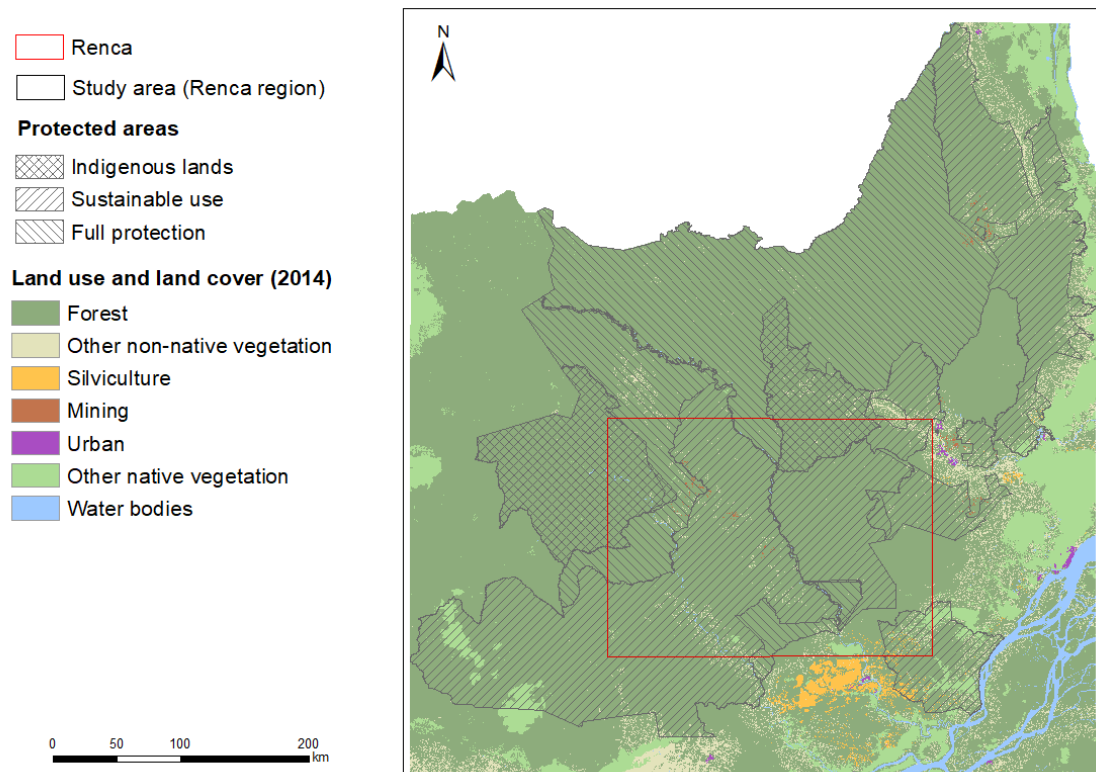


Figure S 1. Renca region and protected areas crossing Renca boundaries

3. Road design information

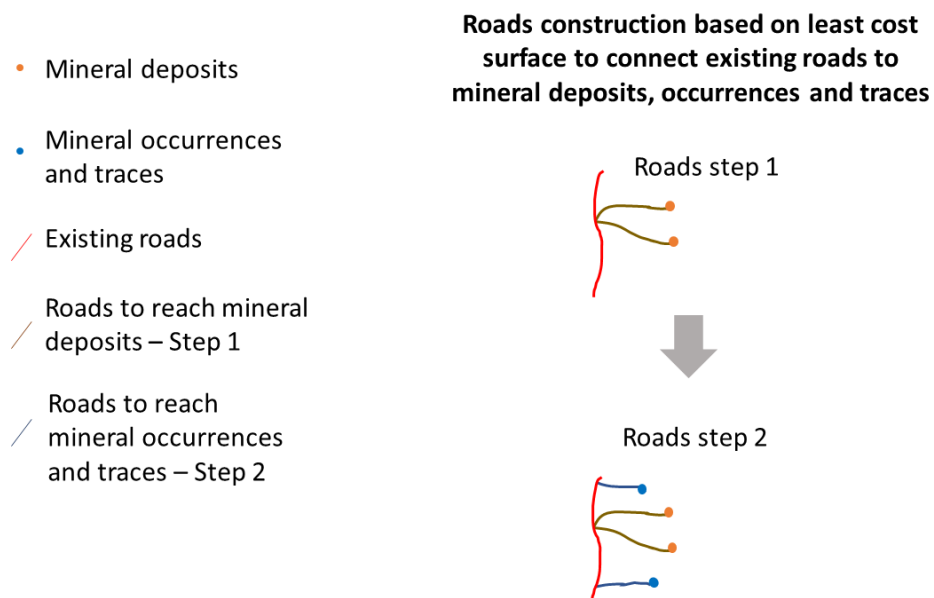


Figure S 2. Mineral information used in the main steps of roads design

4. Mineral occurrences and deforestation surrounding roads in areas with high biological importance

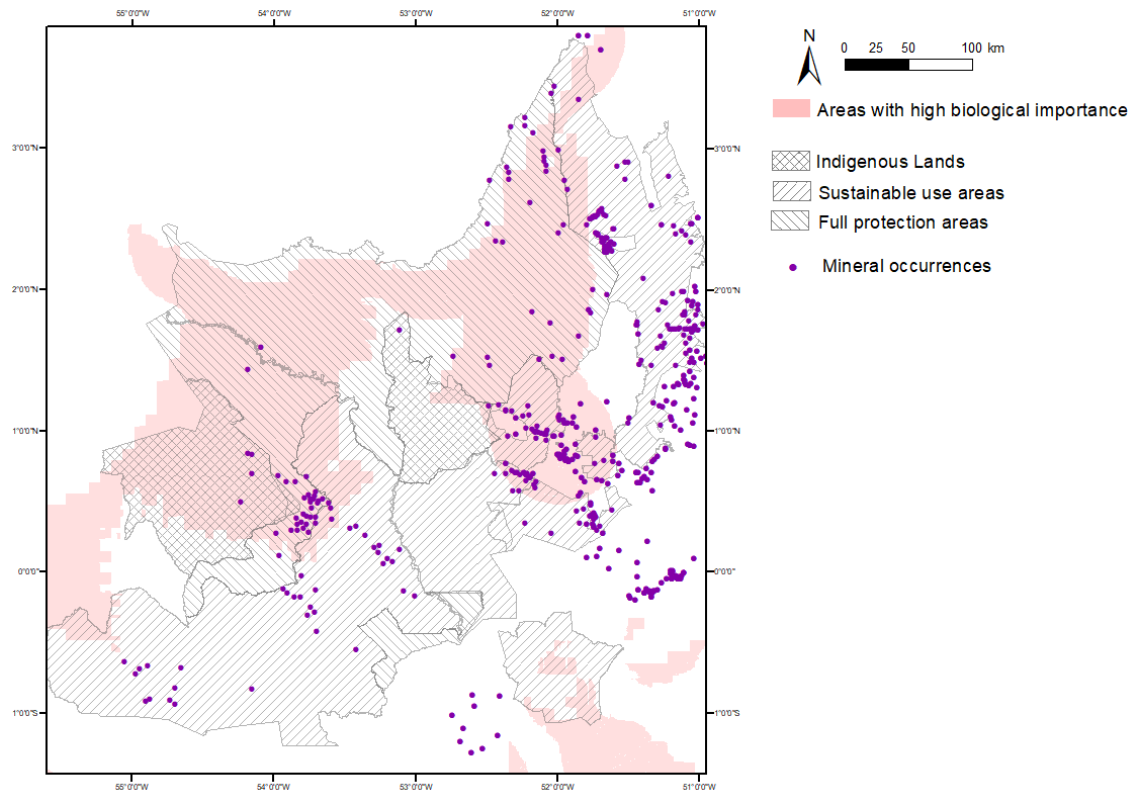


Figure S 3. Areas with high biological importance from Strand et al (2018)

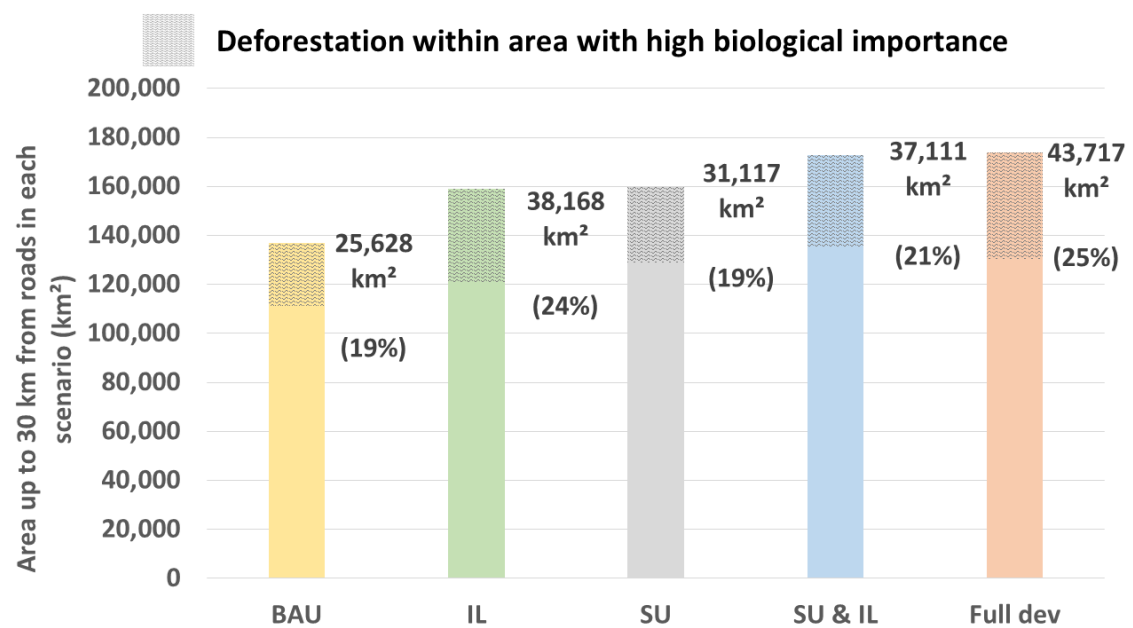


Figure S 4. Deforestation up to 30 km to roads in areas with high biological importance

5. Scenarios parameters

Table S 2. Protected areas extent and percentage of the total landscape

Protected area	Area (km ²)	Percentage of total landscape
Indigenous lands	18,040	6%
Sustainable use	70,369	22%
Full protection	52,072	17%
Under no protection	174,452	55%

Table S 3. Increased non protected area in each scenario used to calculate the increased rates of change

Scenario	Non protected area (km ²)	Increased percentage in relation to BAU scenario
BAU	174,452	-
W_SU	244,821	40%
W_SU_IL	262,861	50%
W_IL	192,492	10%
Full_Dev	314,932	81%

Table S 4. Rates of change used to calibrate and simulate the scenarios (percentage of land that will change from one class to the other)

Transitions	Rates in the calibration		Rates for the scenarios				
	2004-2010	2010-2014	BAU	Weakening sustainable use PAs	Weakening sustainable use and indigenous lands PAs	Weakening indigenous lands PAs	Full development
Forest>Other Non Native Vegetation	0.000899	0.000641	0.000641	0.0008968	0.000961	0.000705	0.001166
Forest>Silviculture	0.000008	0.000003	0.000003	0.0000046	0.000005	0.000004	0.000006
Forest>Mining	0.000007	0.000009	0.000009	0.0000130	0.000014	0.000010	0.000017
Other Non Native Vegetation >Silviculture	0.006811	0.002289	0.002289	0.0032039	0.003433	0.002517	0.004165
Other Non Native Vegetation >Mining	0.000109	0.000247	0.000247	0.0003465	0.000371	0.000272	0.000450

Other Non Native Vegetation >Urban	0.000840	0.000338	0.000338	0.0004737	0.000508	0.000372	0.000616
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*Table S 5. Parameters used to create the friction surface. Sources: Runge, C. A., Tulloch, A. I. T., Gordon, A. & Rhodes, J. R. Quantifying the conservation gains from shared access to linear infrastructure. *Conserv. Biol.* **31**, 1428–1438 (2017) and Dinamica EGO guidebook (https://www.csr.ufmg.br/dinamica/dokuwiki/doku.php?id=lesson_17).*

Variables	Weights	Rationale
Land use and land cover	Forest=5 Other Non Native Vegetation =1 Silviculture=3 Mining=8 Urban=10 Other native vegetation=3 Water bodies=10	Lowest value – basic cost - to areas already cleared The native vegetation, such as forest and others, present an intermediate level of difficulty due to the need for clearing and in some cases license to suppress native forest The highest value to mining, virtually barrier, and water bodies due to necessary to build bridges and large infrastructure
Slope (in degrees)	<1° =1 1 to <5° =2 5 to <10° =3 10 to <15° =4 15 to <20° =5 >=20° = 100	Greater difficulty in building roads with increasing slope

*Table S 6. Values assigned to friction variable to feature the difficulty to road construction considering each scenario. Sources: Runge, C. A., Tulloch, A. I. T., Gordon, A. & Rhodes, J. R. Quantifying the conservation gains from shared access to linear infrastructure. *Conserv. Biol.* **31**, 1428–1438 (2017) and Dinamica EGO guidebook (https://www.csr.ufmg.br/dinamica/dokuwiki/doku.php?id=lesson_17).*

Variables	BAU	Weakening sustainable use PAs	Weakening sustainable use and indigenous lands PAs	Weakening Indigenous lands PAs	Full development
Sustainable use PAs	8	1	1	8	1
Full protection PAs	1000	1000	1000	1000	1
Indigenous lands PAs	1000	1000	1	1	1

6. Land use and land cover database corrections

6.1. Land use and cover dataset

Table S 7. Description of the land use and land cover classes. Available at: <https://www.terraclass.gov.br/geoportal-aml/#webgis>. Source: Almeida CA, Coutinho AC, César J, et al (2008) High spatial resolution land use and land cover mapping of the Brazilian Legal Amazon in 2008 using Landsat-5 / TM and MODIS data. Acta Amaz 46:291–302. <https://doi.org/http://dx.doi.org/10.1590/1809-4392201505504>

Land use and cover classes	Original classes from TerraClass	Description
Forest	Forest (Primary forest featured by dense and heterogeneous formation)	-
Other non-native vegetation	Secondary vegetation (areas that were clear-cut and are at an advanced stage of regeneration with trees and shrubs. Includes areas that were used for forestry (silviculture) or permanent agriculture with use of native or exotic species), herbaceous (pasture in productive process with predominance of herbage and coverage between 90 and 100% by different species of grass) and shrubby pasture (areas of pasture in productive process with predominance of herbage and coverage by species of grass between 50% and 80% associated to the presence of shrubby vegetation with coverage between 20% and 50%), deforestation (areas recently deforested covered by soil, shrubs, herbage and felled trees with no defined land use at this stage, defined as areas that were mapped by PRODES project as deforested in 2008).	Forest in second stage of regeneration and recovered deforested areas. Area cleared with cultivated pasture including areas recently deforested
Silviculture	Silviculture (Plantation of Eucalyptus or Pinus featured by homogenous formation)	-
Urban	Urban (Areas with dense occupation and clear pattern of streets, residential and industrial use)	-
Mining	Mining (Industrial mineral extraction)	
Other native vegetation	Other native vegetation and no forest (areas in the limits of the Brazilian Amazon without forest)	Areas featured by non-forest native vegetation, such as mangroves and flooded fields
Water bodies	Hydrography	

6.2. Dataset pre-process

Table S 8. Changes in the land use and cover classes to correct transitions not important for the model calibration

Step	Land use and land cover TerraClass dataset	Change	Rationale
1°	Non observed	Pixels with non-observed areas (clouds) were assigned with value of pixels of previous land use and land cover	Although the cloud cover was less than 1% in all years of analysis, the transitions involving non-observed areas were deleted and they are not relevant for model calibration
2°	Water bodies	Pixels assigned with water bodies in at least one year (2004 or 2010 or 2014) was assigned as water bodies in all other years	A water bodies mask was made to correct transitions of other land uses and cover to water bodies and vice-versa
3°	Other native vegetation	Pixels classified with other native vegetation in at least one year (2004 or 2010 or 2014) was assigned as other native vegetation in all other years	The other native vegetation represents the vegetation cover in the Amazon fringe, including flooded areas and mangroves. As the focus was modeling mining and infrastructure expansion over mainly forests, the transitions with other native vegetation was not considered in the model calibration

Table S 9. Corrections in land use and land cover classes considering the expansion of mining, urban infrastructure, and forest plantation in the region

Step	Land use and land cover TerraClass dataset	Rationale
1°	Mining	No mines were closed in the years of 2004-2014, therefore, we considered that mining activities are expanding in the region
2°	Silviculture	The area of forest plantation expanded during the year of analysis due to the increased activities of the Jari project
3°	Urban	The new infrastructure, including new mining projects and silviculture expansion, induced human occupation and urban growth

Table S 10. Corrections to fix the transitions of interest in the TerraClass dataset

Transition in TerraClass dataset	Reclassified	Assumptions
2004 Other Non-Native Vegetation > 2010 Forest > 2014 Other Non-Native Vegetation	2004 Other Non-Native Vegetation > 2010 Other Non-Native Vegetation > 2014 Other Non-Native Vegetation	The area was always other non-native vegetation
2004 Other Non-Native Vegetation > 2010 Forest > 2014 Mining	2004 Other Non-Native Vegetation > 2010 Mining > 2014 Mining	The area was converted to mining already in 2010
2004 Other Non-Native Vegetation > 2010 Forest > 2014 Silviculture	2004 Other Non-Native Vegetation > 2010 Silviculture > 2014 Silviculture	The area was converted to silviculture already in 2010
2004 Other Non-Native Vegetation > 2010 Forest > 2014 Urban	2004 Other Non-Native Vegetation > 2010 Urban > 2014 Urban	The area was converted to urban already in 2010
2004 Other Non-Native Vegetation > 2010 Forest > 2014 Forest	2004 Forest > 2010 Forest > 2014 Forest	The pixel was considered permanently as forest
2004 Forest > 2010 Other Non-	2004 Forest > 2010 Forest > 2014 Forest	The pixel was considered

Native Vegetation > 2014 Forest		permanently as forest
2004 Other Non-Native Vegetation > 2010 Other Non-Native Vegetation > 2014 Forest	2004 Other Non-Native Vegetation > 2010 Other Non-Native Vegetation > 2014 Other Non-Native Vegetation	The pixel was considered permanently as other non-native vegetation

Table S 11. Number of cells and percentage of landscape considering each land use and cover before and after resampling the cells size in 2004

Land use and land cover	2004			
	Original (30 m cells)		Resampled (100 m cells)	
	Area (km ²)	Percentage of landscape	Area (km ²)	Percentage of landscape
Primary forest	224205	89.1%	224335	89.1%
Secondary vegetation	1303	0.5%	1306	0.5%
Silviculture	744	0.3%	743	0.3%
Shrubby pasture	744	0.3%	744	0.3%
Herbaceous pasture	339	0.1%	339	0.1%
Mining	6	0.002%	6	0.002%
Urban	80	0.032%	80	0.03%
Others	101	0.040%	101	0.04%
Non-observed	1002	0.4%	1002	0.4%
Deforestation	106	0.04%	105	0.04%
No forest	18646	7.4%	18659	7.4%
Water bodies	4302	1.7%	4303	1.7%

Table S 12. Number of cells and percentage of landscape considering each land use and cover before and after resampling the cells size in 2010

Land use and land cover	2010			
	Original (30 m cells)		Resampled (100 m cells)	
	Area (km ²)	Percentage of landscape	Area (km ²)	Percentage of landscape
Primary forest	222287	88.4%	222417	88.4%
Secondary vegetation	1752	0.7%	1753	0.7%
Silviculture	781	0.3%	781	0.3%
Shrubby pasture	1022	0.4%	1022	0.4%
Herbaceous pasture	496	0.2%	497	0.2%
Mining	19	0.01%	19	0.01%
Urban	94	0.04%	94	0.04%
Others	84	0.03%	83	0.03%
Non-observed	1960	0.8%	1960	0.8%
Deforestation	136	0.1%	136	0.1%
No forest	18646	7.4%	18659	7.4%
Water bodies	4302	1.7%	4303	1.7%

Table S 13. Number of cells and percentage of landscape considering each land use and cover before and after resampling the cells size in 2014

Land use and land cover	2014			
	Original (30 m cells)		Resampled (100 m cells)	
	Area (km ²)	Percentage of landscape	Area (km ²)	Percentage of landscape
Primary forest	222495	88.4%	222624	88.4%
Secondary vegetation	2040	0.8%	2041	0.8%
Silviculture	743	0.3%	743	0.3%
Shrubby pasture	1323	0.5%	1323	0.5%
Herbaceous pasture	1290	0.5%	1291	0.5%
Mining	31	0.01%	31	0.01%
Urban	103	0.04%	104	0.04%
Others	249	0.1%	248	0.1%
Non-observed	303	0.1%	303	0.1%
Deforestation	53	0.02%	54	0.02%
No forest	18646	7.4%	18659	7.4%
Water bodies	4302	1.7%	4303	1.7%

Table S 14. Area (km²) and percentage of landscape considering each land use and cover before and after the dataset preprocessing in 2004

Land use and land cover	2004			
	Before	%	After	%
Forest	224,335	89.2%	224599	89.2%
Other Non-Native Vegetation	2,494	1.0%	2840	1.1%
Silviculture	744	0.3%	837	0.3%
Mining	6	0.002%	6	0.002%
Urban	80	0.032%	83	0.03%
Other Native Vegetation	18,760	7.5%	19040	7.6%
Water bodies	4,303	1.7%	4319	1.7%
Non-observed	1,002	0.4	-	0%

Table S 15. Area (km²) and percentage of landscape considering each land use and cover before and after the dataset preprocessing in 2010

Land use and land cover	2010			
	Before	%	After	%
Forest	222,417	89.1%	223,372	88.7%
Other Non-Native Vegetation	3,408	1.4%	3,896	1.5%
Silviculture	781	0.3%	982	0.4%
Mining	19	0.01%	18	0.007%
Urban	94	0.04%	97	0.04%
Other Native Vegetation	18,742	7.5%	19,040	7.6%
Water bodies	4,303	1.7%	4,319	1.7%
Non-observed	1,960	0.8%	-	0%

Table S 16. Area (km²) and percentage of landscape considering each land use and cover before and after the dataset preprocessing in 2014

Land use and land cover	2014			
	%	Before	%	After
Forest	222,624	88.5%	222,789	88.5%
Other Non-Native Vegetation	4,709	1.9%	4,421	1.8%
Silviculture	743	0.3%	1,023	0.4%
Mining	31	0.01%	31	0.012%
Urban	104	0.04%	102	0.04%
Other Native Vegetation	18,907	7.5%	19,040	7.6%
Water bodies	4,303	1.7%	4,319	1.7%
Non-observed	303	0.01%	-	0%

7. Weights of Evidence used in the model calibration



Figure S 5. Weights of Evidence (WoE) used to calibrate the transition of forest to other non-native vegetation (ONNV)

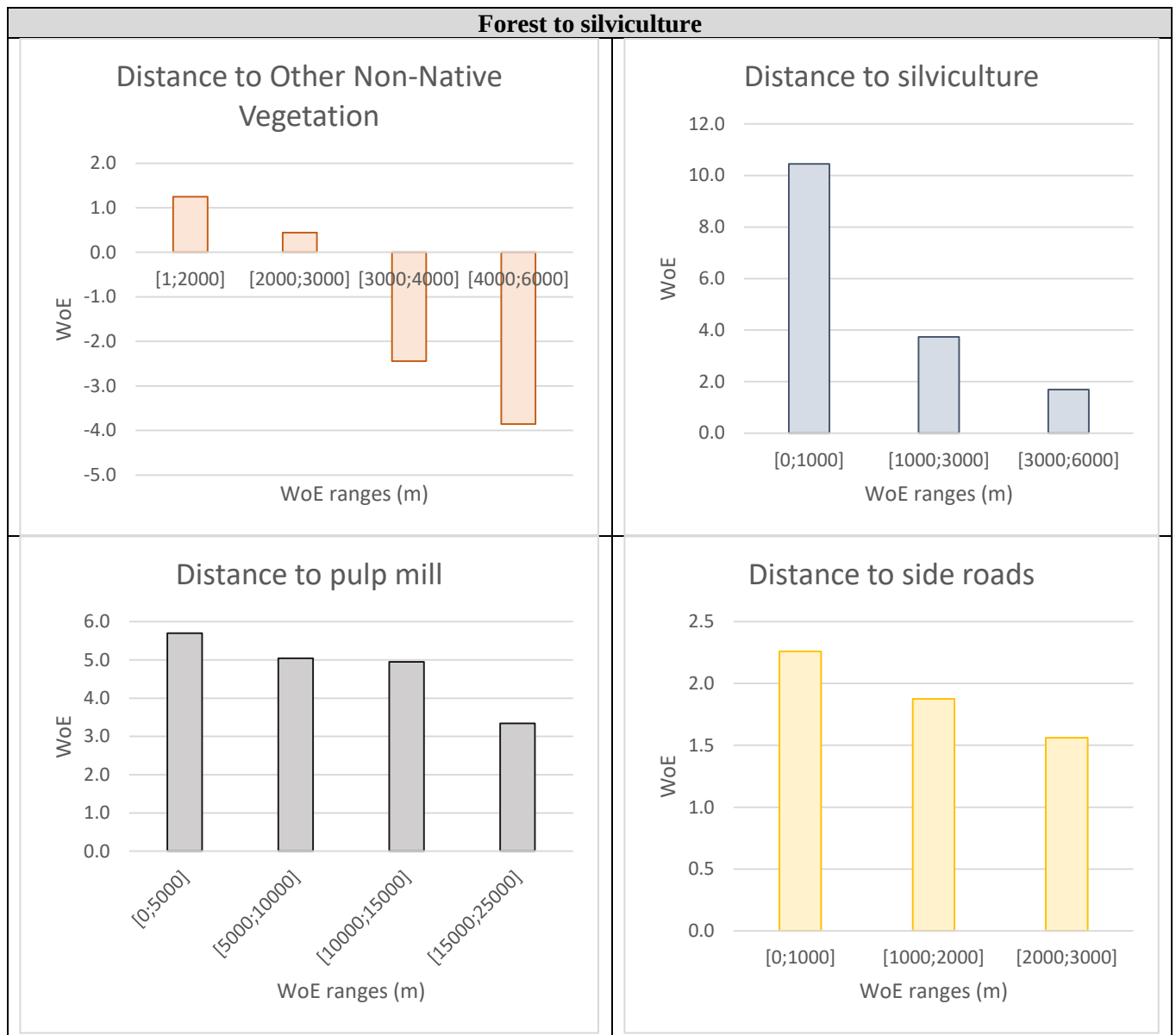


Figure S 6. Weights of Evidence used to calibrate the transition of forest to silviculture

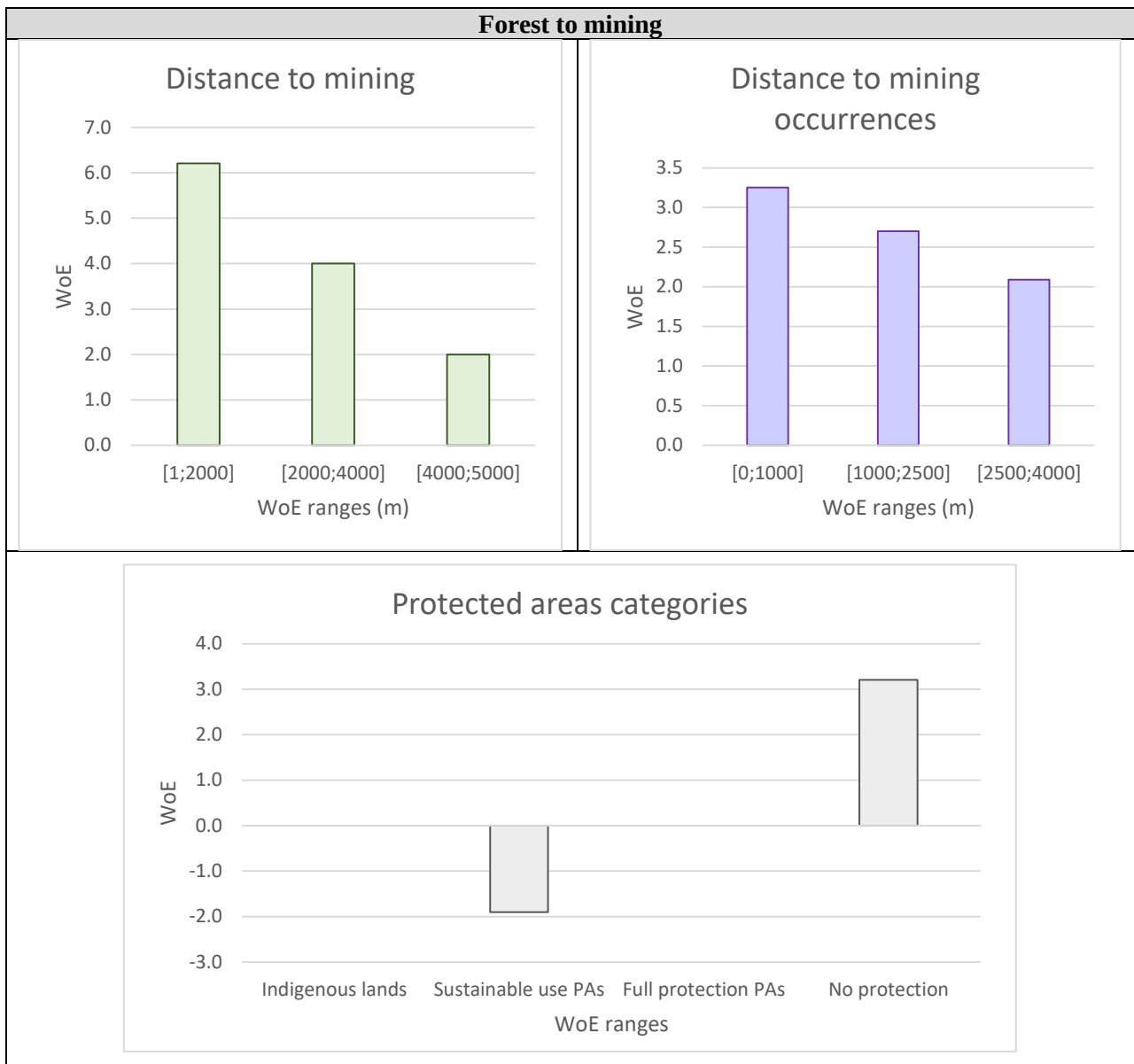


Figure S 7. Weights of Evidence used to calibrate the transition of forest to mining

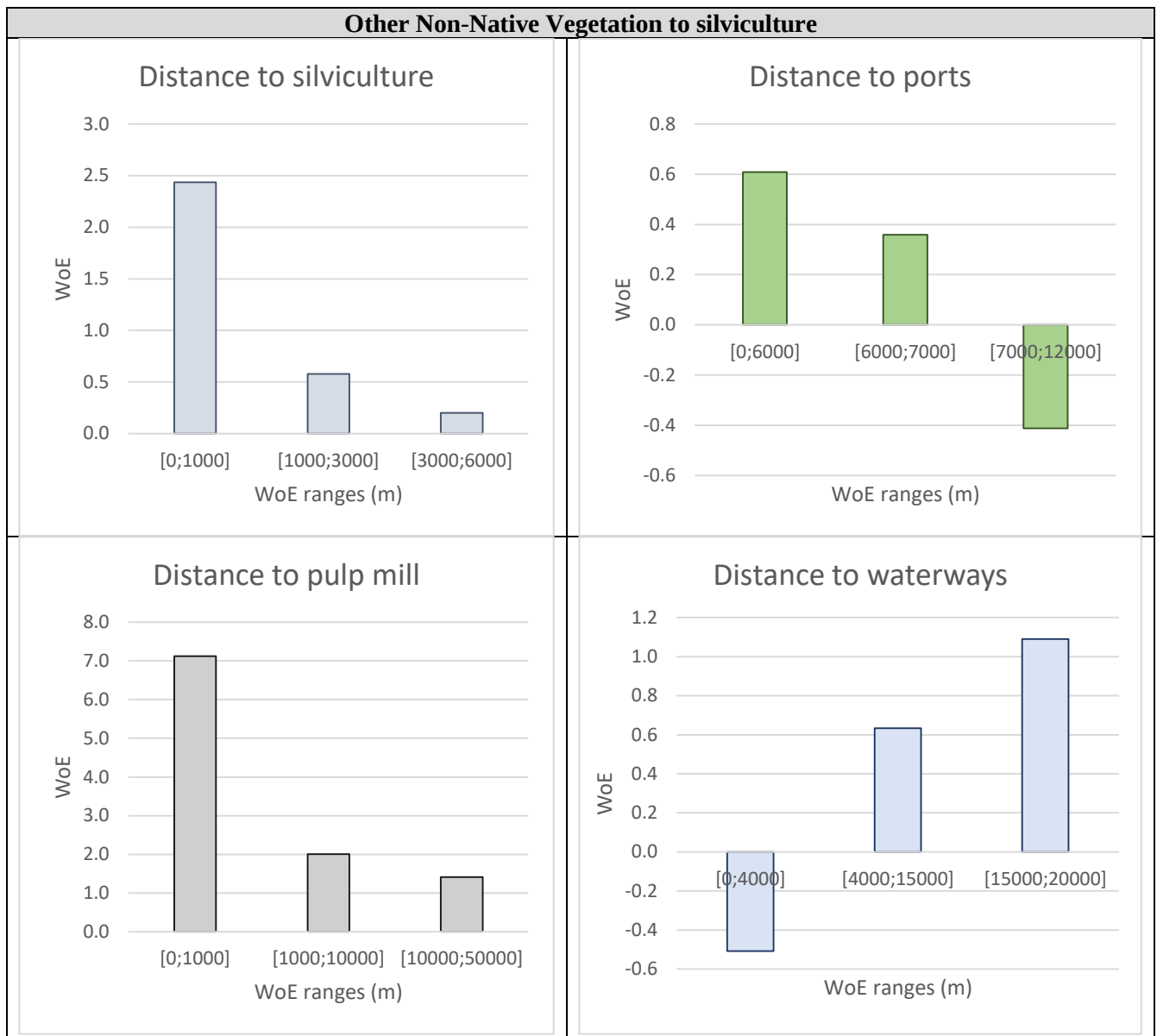


Figure S 8. Weights of Evidence used to calibrate the transition of other non-native vegetation (ONNV) to silviculture

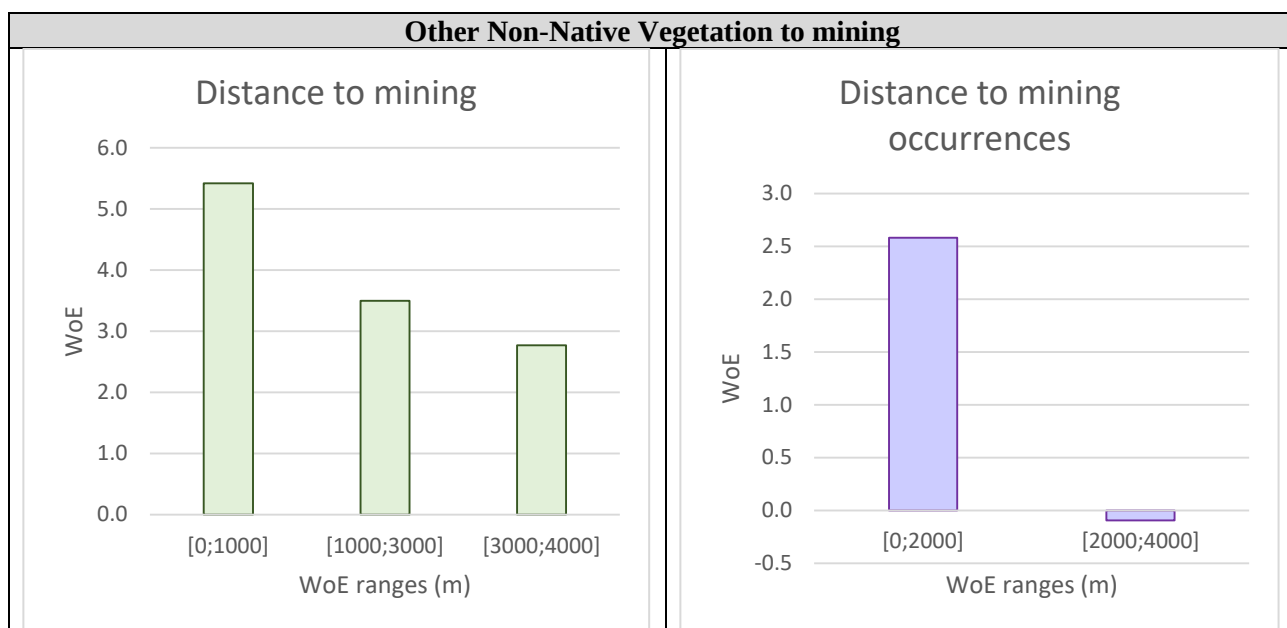


Figure S 9. Weights of Evidence used to calibrate the transition of other non-native vegetation (ONNV) to mining



Figure S 10. Weights of Evidence used to calibrate the transition of other non-native vegetation (ONNV) to urban

8. Validation curves of the calibrated and null models



Figure S 11. Validation curve comparing the calibrated and null model for all transitions

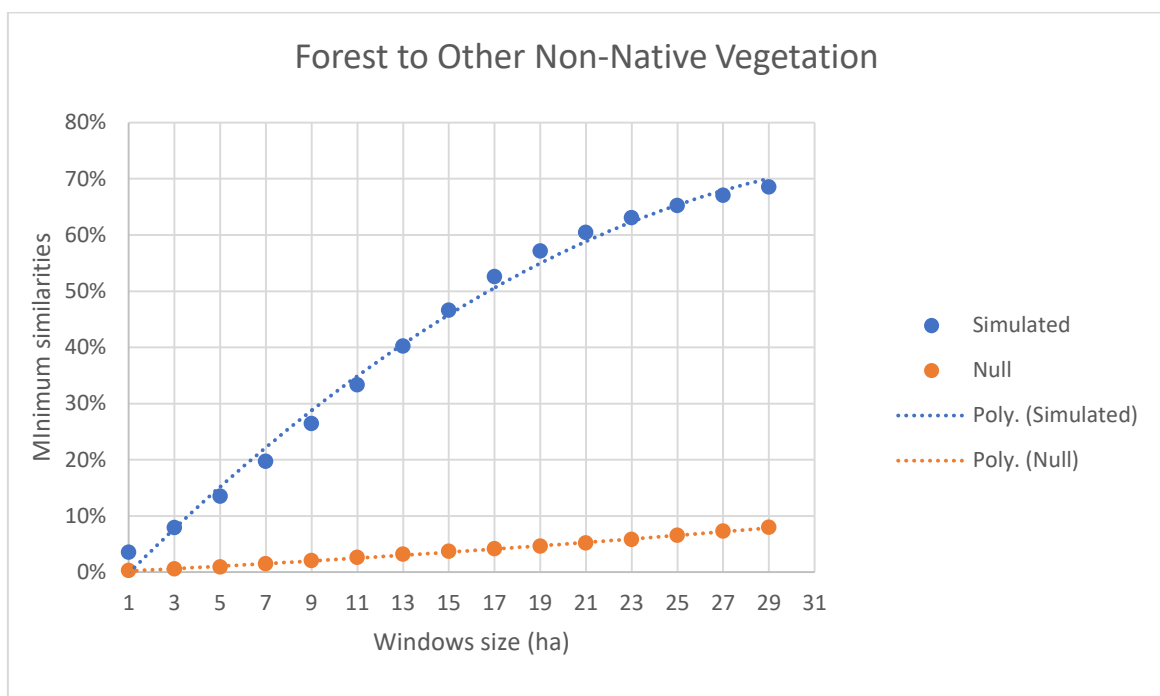


Figure S 12. Validation curve comparing the calibrated and null model for the transition of forest to other non-native vegetation (ONNV)

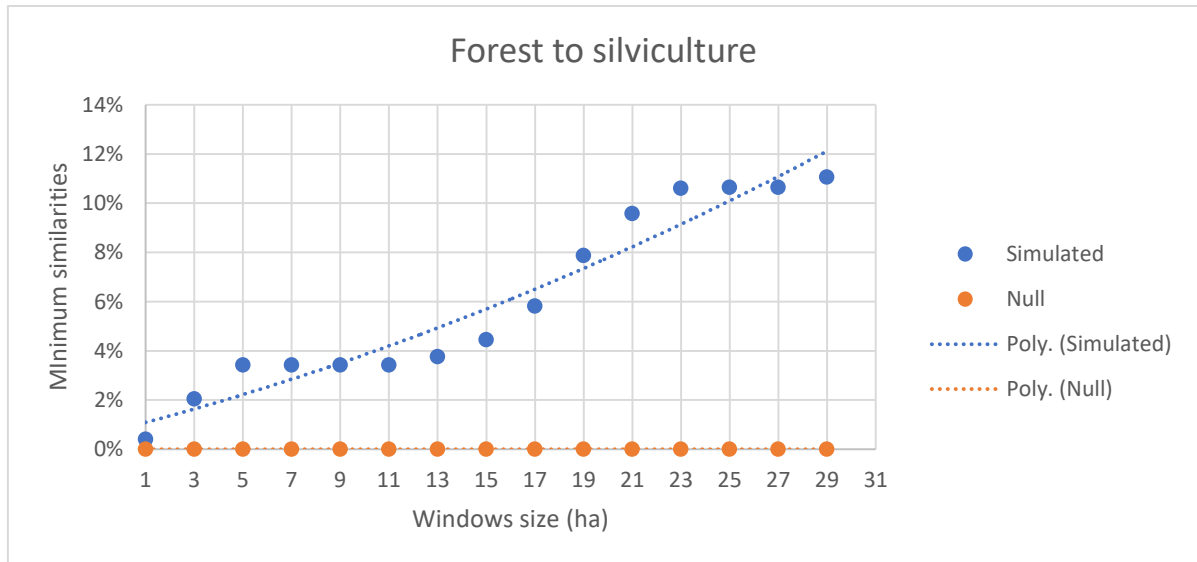


Figure S 13. Validation curve comparing the calibrated and null model for the transition of forest to silviculture

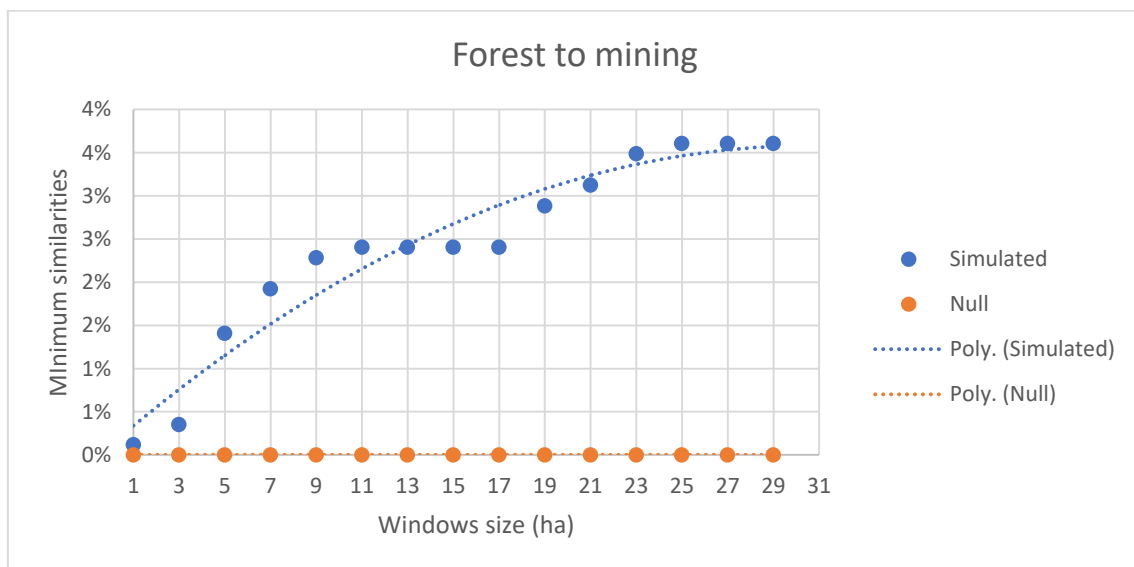


Figure S 14. Validation curve comparing the calibrated and null model for the transition of forest to mining

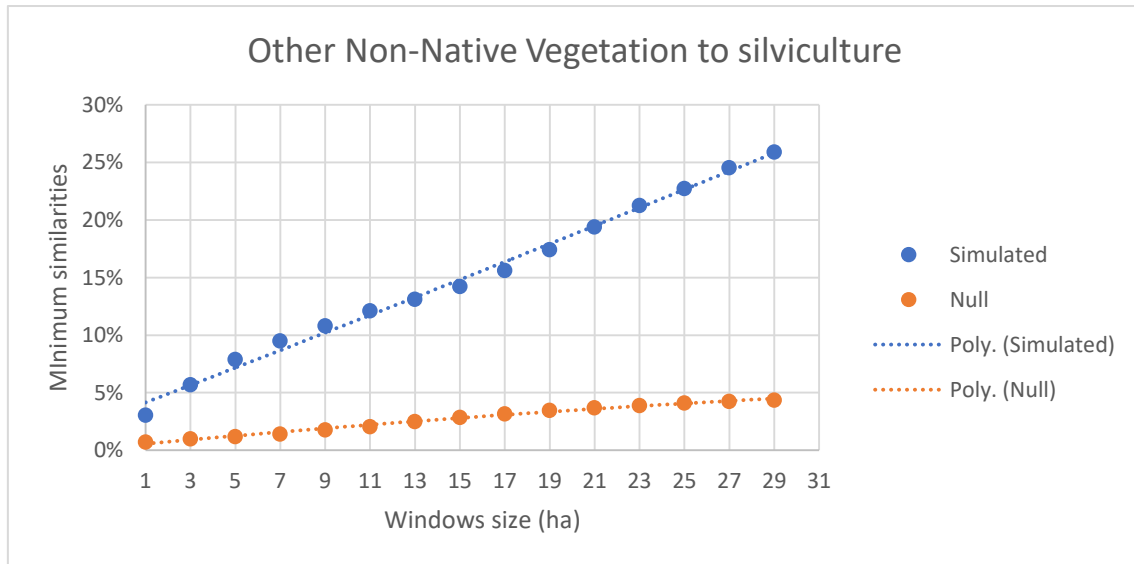


Figure S 15. Validation curve comparing the calibrated and null model for the transition of other non-native vegetation (ONNV) to silviculture

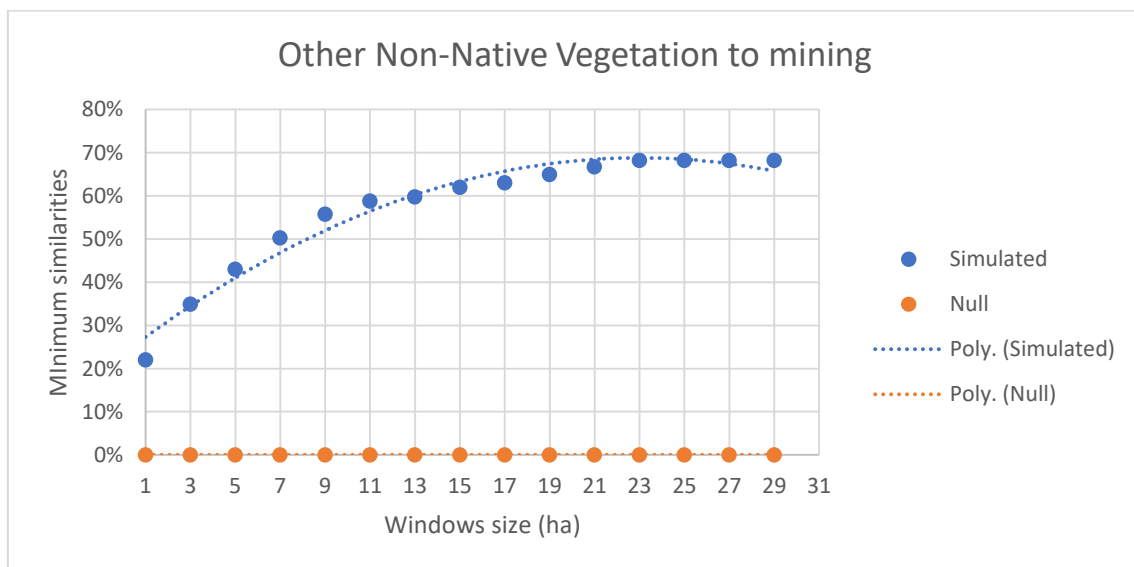


Figure S 16. Validation curve comparing the calibrated and null model for the transition of other non-native vegetation (ONNV) to mining

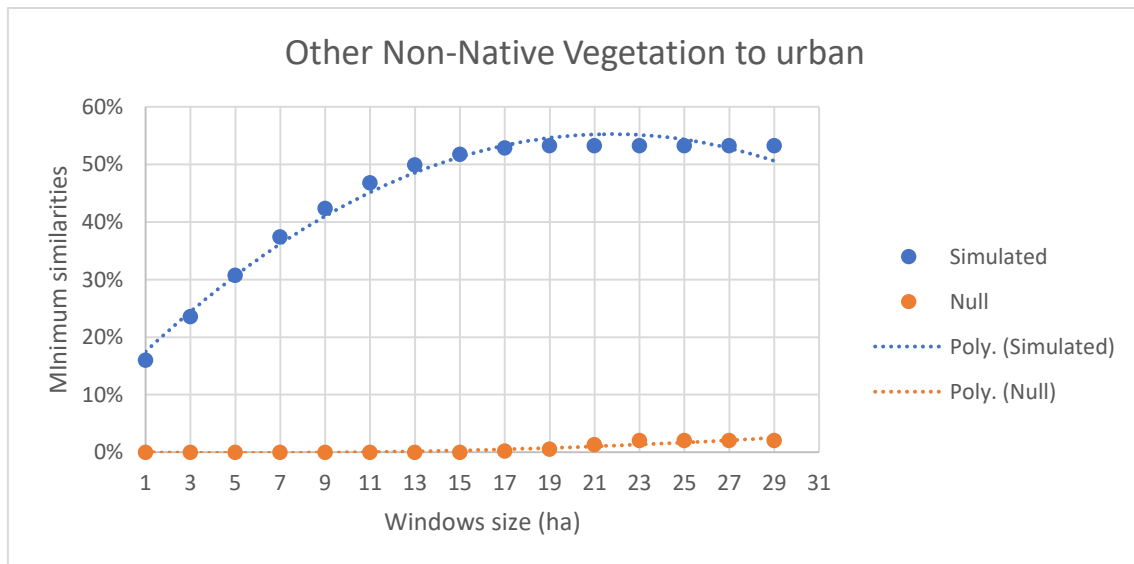


Figure S 17. Validation curve comparing the calibrated and null model for the transition of other non-native vegetation (ONNV) to urban