Supplementary information

1. **Study region**

Table S 1. Protected areas in the study region. Source: MMA

|  |  |  |
| --- | --- | --- |
| **Name** | **Category** | **Year of creation** |
| Parque Nacional da Serra do Cipó | Full protection | 1984 |
| Área de Proteção Ambiental Morro Da Pedreira | Sustainable use | 1990 |
| Área de Proteção Ambiental Águas Vertentes | Sustainable use | 1998 |
| Parque Estadual Pico do Itambé | Full protection | 1998 |
| Parque Natural Municipal Salão de Pedras | Full protection | 1999 |
| Área de Proteção Ambiental do Itacuru | Sustainable use | 2001 |
| Monumento Natural Municipal Serra da Ferrugem | Full protection | 2007 |
| Parque Estadual Serra do Intendente | Full protection | 2007 |
| Monumento Natural Estadual Várzea do Lageado e Serra do Raio | Full protection | 2011 |
| Reserva Particular do Patrimônio Natural Aves Gerais | Sustainable use | 2012 |
| Parque Natural Municipal do Tabuleiro | Full protection | 2013 |

1. **Dataset fixing**

Table S 2. Land use and land cover classes description

|  |  |
| --- | --- |
| **Land use and land cover** | **Description** |
| Pastureland | Areas with natural or planted pasture. In some cases, associated to agriculture |
| Fields | Grassland, in some cases associated to high altitudes, and rocky outcrops |
| Silviculture | Forest plantations |
| Forest | Forest formation |
| Mining | Exposed soil with mining infrastructure |
| Urban | Urbanized areas with non-vegetated surfaces, including roads and building infrastructures |
| Hidrography | Rivers, lakes and water bodies |

Table S 3. Land use and land cover compatibilization

|  |  |
| --- | --- |
| **Land use and land cover (final)** | **Land use and land cover original from MapBiomas Coleção 5** |
| Pastureland | Savanna formation |
| Pasture |
| Mosaic of agriculture and pasture |
| Fields | Grassland |
| Rocky outcrops |
| Other non-vegetated area\* |
| Silviculture | Silviculture |
| Forest | Forest formation |
| Mining | Mining |
| Urban | Urban |
| Hydrography | Hydrography |

\* Spatial distribution in the study area corresponds to rupestrian grasslands as shown by:

Fernandes, G.W., Barbosa, N.P.U., Alberton, B., Barbieri, A., Dirzo, R., Goulart, F., Guerra, T.J., Morellato, L.P.C., Solar, R.R.C., 2018. The deadly route to collapse and the uncertain fate of Brazilian rupestrian grasslands. Biodivers. Conserv. 27, 2587–2603. <https://doi.org/10.1007/s10531-018-1556-4>

Silveira, F.A.O., Negreiros, D., Barbosa, N.P.U., Buisson, E., Carmo, F.F., Carstensen, D.W., Conceição, A.A., Cornelissen, T.G., Echternacht, L., Fernandes, G.W., Garcia, Q.S., Guerra, T.J., Jacobi, C.M., Lemos-Filho, J.P., Le Stradic, S., Morellato, L.P.C., Neves, F.S., Oliveira, R.S., Schaefer, C.E., Viana, P.L., Lambers, H., 2016. Ecology and evolution of plant diversity in the endangered campo rupestre: a neglected conservation priority. Plant Soil 403, 129–152. https://doi.org/10.1007/s11104-015-2637-8

Table S 4. Evaluation of dataset fixing in 1986

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **1986** | **Original dataset** | | **Adjustments** | **Reclassification** | | **Modeling pre-processing** | |
| **Land use and land cover MapBiomas Coleção 5** | **Area (ha)** | **Percentage of the landscape (%)** | **Land use and land cover classes** | **Area (ha)** | **Percentage of the landscape (%)** | **Area (ha)** | **Percentage of the landscape (%)** |
| Forest | 304038 | 38.9% | Forest | 304038 | 38.9% | 298329 | 38.9% |
| Savanna formation | 148243 | 19.0% | Pastureland | 376195 | 48.2% | 367973 | 48.0% |
| Pastureland | 168120 | 21.5% |
| Mosaic of agriculture and pasture | 59832 | 7.7% |
| Grasslands | 73980 | 9.5% | Fields | 96196 | 12.3% | 94357 | 12.3% |
| Rocky outcrops\* | 8045 | 1.0% |
| Other non-vegetated area | 14170 | 1.8% |
| Silviculture | 4009 | 0.5% | Silviculture | 4009 | 0.5% | 5019 | 0.7% |
| Mining | 71 | 0.01% | Mining | 71 | 0.01% | - | - |
| Urban | 194 | 0.02% | Urban | 194 | 0.02% | 195 | 0.03% |
| Hydrography | 548 | 0.07% | Hydrography | 548 | 0.07% | 689 | 0.09% |

Table S 5. Evaluation of dataset fixing in 1993

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **1993** | **Original dataset** | | **Adjustments** | **Reclassification** | | **Modeling pre-processing** | |
| **Land use and land cover MapBiomas Coleção 5** | **Area (ha)** | **Percentage of the landscape (%)** | **Land use and land cover classes** | **Area (ha)** | **Land use and land cover MapBiomas Coleção 5** | **Area (ha)** | **Percentage of the landscape (%)** |
| Forest | 316101 | 40.5% | Forest | 316101 | 40.5% | 309734 | 40% |
| Savanna formation | 136033 | 17.4% | Pastureland | 359909 | 46.1% | 352312 | 46% |
| Pastureland | 179234 | 22.9% |
| Mosaic of agriculture and pasture | 44642 | 5.7% |
| Grasslands | 76575 | 9.8% | Fields | 99086 | 12.7% | 97273 | 13% |
| Rocky outcrops\* | 10138 | 1.3% |
| Other non-vegetated area | 12373 | 1.6% |
| Silviculture | 5332 | 0.7% | Silviculture | 5332 | 0.7% | 6359 | 0.8% |
| Mining | 85 | 0.01% | Mining | 85 | 0.01% | - | - |
| Urban | 342 | 0.04% | Urban | 342 | 0.04% | 195 | 0.03% |
| Hydrography | 396 | 0.05% | Hydrography | 396 | 0.05% | 689 | 0.09% |

Table S 6. Evaluation of dataset fixing in 1999

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **1999** | **Original dataset** | | **Adjustments** | **Reclassification** | | **Modeling pre-processing** | |
| **Land use and land cover MapBiomas Coleção 5** | **Area (ha)** | **Percentage of the landscape (%)** | **Land use and land cover classes** | **Area (ha)** | **Land use and land cover MapBiomas Coleção 5** | **Area (ha)** | **Percentage of the landscape (%)** |
| Forest | 316520 | 40.5% | Forest | 316520 | 40.5% | 310174 | 40.5% |
| Savanna formation | 140759 | 18.0% | Pastureland | 357160 | 45.7% | 350490 | 45.7% |
| Pastureland | 166820 | 21.4% |
| Mosaic of agriculture and pasture | 49580 | 6.3% |
| Grasslands | 74716 | 9.6% | Fields | 99712 | 12.8% | 97854 | 12.8% |
| Rocky outcrops\* | 10968 | 1.4% |
| Other non-vegetated area | 14028 | 1.8% |
| Silviculture | 6769 | 0.9% | Silviculture | 6769 | 0.9% | 7160 | 0.9% |
| Mining | 84 | 0.01% | Mining | 84 | 0.01% | - | - |
| Urban | 390 | 0.05% | Urban | 390 | 0.05% | 195 | 0.03% |
| Hydrography | 616 | 0.08% | Hydrography | 616 | 0.08% | 689 | 0.09% |

1. **Modeling**

Figure S 1. Transitions of interest modeled

Diagrama

Descrição gerada automaticamente

Table S 7. Annual transitions (percentages) used for calibration (1986-1993) and validation (1993-1999)

|  |  |  |  |
| --- | --- | --- | --- |
| **From** | **To** | **Years of analysis** | |
| **1986 - 1993** | **1993 - 1999** |
| Forest | Silviculture | 0.00067 | 0.00045 |
| Forest | Pastureland | 0.01196 | 0.01463 |
| Pastureland | Forest | 0.01514 | 0.01350 |
| Pastureland | Fields | 0.00239 | 0.00191 |
| Fields | Pastureland | 0.00472 | 0.00585 |

Table S 8. Description of explanatory variables and sources of information

|  |  |  |
| --- | --- | --- |
| **Variables** | **Description** | **Sources** |
| Static | Distance to rivers | ANA |
| Distance to roads | Plano Nacional de Transportes (DNIT)/ IBGE |
| Distance to urban centers | Censo 2010 |
| Conservation units | MMA |
| Slope | United States Geological Survey (USGS) |
| Dynamic | Distance to forest | Land use and land cover maps |
| Distance to fields |
| Distance to pastureland |
| Distance to silviculture |

Figure S 2. Model validation curve comparing the model calibrated with the null

Figure S 3. Area converted in the counterfactual and observed landscapes in 2008-2019

Figure S 4. Forest cover in the study region considering the observed and simulated counterfactual landscape during 1985 and 2019

Gráfico, Gráfico de barras, Histograma

Descrição gerada automaticamente

1. **Ecosystem services evaluation**

The question proposed for the supply matrix was “What is the capacity of each LULC to provide ecosystem services?” to be evaluated in the range of 0 (no relevant capacity) to 5 (very high supply capacity).

Table S 9. Ecosystem services matrix for evaluating the supply

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Provisioning services** | | | | | **Regulating services** | | | | | |
| Land use and  land cover classes | Food | Raw materials | Fresh water | Medicinal resources | Local climate and air quality regulation | Carbon sequestration and storage | Moderation of extreme events | Wastewater treatment | Erosion prevention and maintenance of soil fertility | Pollination | Biological control |
| Hydrography | **4.5** | **4** | **5** | **3.5** | **3** | **3** | **4.5** | **5** | **3** | **0** | **3.5** |
| Forest | **5** | **5** | **4.5** | **5** | **5** | **5** | **5** | **4.5** | **5** | **5** | **5** |
| Fields | **1** | **1** | **3** | **3.5** | **4.5** | **2.5** | **4.5** | **1.5** | **4.5** | **4.5** | **4.5** |
| Pastureland | **4** | **3** | **1** | **1** | **1** | **1** | **1** | **1** | **1.5** | **2** | **1** |
| Silviculture | **0.5** | **5** | **1** | **1** | **2.5** | **4** | **3** | **1** | **2** | **1.5** | **1** |
| Urban | **0.5** | **0** | **1** | **0.5** | **1** | **0.5** | **1** | **3.5** | **1** | **1** | **0.5** |
| Mining | **0** | **4.5** | **1** | **0** | **0.5** | **0** | **0.5** | **0.5** | **0.5** | **0.5** | **0.5** |

Median values in a scale from 0 (no supply) to 5 (maximum supply)

The question proposed for the demand matrix was “What is the capacity of each LULC to demand ecosystem services?” using a scale of 0 (no relevant demand) to 5 (very high demand capacity).

Table S 10. Ecosystem services matrix to evaluate the demand

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Provisioning services** | | | | | **Regulating services** | | | | | |
| Land use and  land cover classes | Food | Raw materials | Fresh water | Medicinal resources | Local climate and air quality regulation | Carbon sequestration and storage | Moderation of extreme events | Wastewater treatment | Erosion prevention and maintenance of soil fertility | Pollination | Biological control |
| Hydrography | **0** | **0** | **0** | **0** | **0.5** | **0** | **0.5** | **3.5** | **1** | **0** | **0.5** |
| Forest | **0** | **0** | **2** | **0** | **3** | **0** | **2.5** | **2.5** | **2.5** | **3.5** | **2** |
| Fields | **0.5** | **0** | **2.5** | **0** | **2.5** | **1** | **3** | **0.5** | **3** | **3.5** | **1.5** |
| Pastureland | **0.5** | **2** | **5** | **0** | **4.5** | **2** | **4.5** | **4** | **4.5** | **5** | **4.5** |
| Silviculture | **0** | **0** | **3.5** | **0** | **3.5** | **2** | **3.5** | **2.5** | **4** | **2.5** | **4** |
| Urban | **5** | **5** | **5** | **5** | **5** | **5** | **5** | **5** | **4.5** | **2** | **3** |
| Mining | **0** | **4** | **4.5** | **0** | **1** | **0** | **2** | **4** | **3** | **0** | **0** |

Median values in a scale from 0 (no demand) to 5 (maximum demand)

Table S 11. Ecosystem services matrix for the budget

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Provisioning services** | | | | | | **Regulating services** | | | | | |
| Land use and  land cover classes | Food | Raw materials | Fresh water | Medicinal resources | Local climate and air quality regulation | Carbon sequestration and storage | | Moderation of extreme events | Wastewater treatment | Erosion prevention and maintenance of soil fertility | Pollination | Biological control |
| Hydrography | **4.5** | **4** | **5** | **3.5** | **2.5** | **3** | | **4** | **1.5** | **2** | **0** | **3** |
| Forest | **5** | **5** | **2.5** | **5** | **2** | **5** | | **2.5** | **2** | **2.5** | **1.5** | **3** |
| Fields | **0.5** | **1** | **0.5** | **3.5** | **2** | **1.5** | | **1.5** | **1** | **1.5** | **1** | **3** |
| Pastureland | **3.5** | **1** | **-4** | **1** | **-3.5** | **-1** | | **-3.5** | **-3** | **-3** | **-3** | **-3.5** |
| Silviculture | **0.5** | **5** | **-2.5** | **1** | **-1** | **2** | | **-0.5** | **-1.5** | **-2** | **-1** | **-3** |
| Urban | **-4.5** | **-5** | **-4** | **-4.5** | **-4** | **-4.5** | | **-4** | **-1.5** | **-3.5** | **-1** | **-2.5** |
| Mining | **0** | **0.5** | **-3.5** | **0** | **-0.5** | **0** | | **-1.5** | **-3.5** | **-2.5** | **0.5** | **0.5** |

Budgets values in a scale from -5 (demand exceed the supply) to 5 (supply exceeds the demand)

Table S 12. Standard deviation of ecosystem services supply matrix

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Provisioning services | | | | | Regulating services | | | | | | |
| Land use and land cover classes | Food | Raw materials | Fresh water | Medicinal resources | Local climate and air quality regulation | | Carbon sequestration and storage | Moderation of extreme events | Wastewater treatment | Erosion prevention and maintenance of soil fertility | Pollination | Biological control |
| Pastureland | 0.82 | 0.82 | 0.00 | 0.82 | 0.50 | | 0.82 | 0.50 | 0.50 | 0.58 | 1.15 | 0.50 |
| Fields | 2.00 | 2.00 | 2.63 | 1.71 | 1.89 | | 2.06 | 1.41 | 2.16 | 1.41 | 1.89 | 1.89 |
| Silviculture | 1.89 | 1.00 | 1.73 | 0.82 | 0.96 | | 1.50 | 0.50 | 0.82 | 1.26 | 1.41 | 0.50 |
| Forest | 0.50 | 1.00 | 1.41 | 0.00 | 0.00 | | 0.00 | 0.00 | 1.89 | 0.00 | 0.00 | 0.50 |
| Mining | 0.50 | 0.96 | 0.82 | 0.50 | 0.58 | | 0.50 | 0.96 | 0.58 | 0.58 | 0.58 | 0.58 |
| Urban | 0.58 | 0.50 | 1.26 | 0.96 | 0.50 | | 0.58 | 0.50 | 2.45 | 0.50 | 0.82 | 0.58 |
| Hydrography | 0.58 | 2.36 | 0.00 | 1.71 | 2.22 | | 1.50 | 0.58 | 2.50 | 2.22 | 1.00 | 1.29 |

Table S 13. Standard deviation of ecosystem services demand matrix

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Provisioning services | | | | | Regulating services | | | | | | |
| Land use and land cover classes | Food | Raw materials | Fresh water | Medicinal resources | Local climate and air quality regulation | | Carbon sequestration and storage | Moderation of extreme events | Wastewater treatment | Erosion prevention and maintenance of soil fertility | Pollination | Biological control |
| Pastureland | 1.89 | 1.91 | 1.00 | 0.50 | 1.41 | | 1.63 | 0.96 | 1.50 | 0.96 | 1.00 | 0.96 |
| Fields | 0.96 | 0.50 | 1.71 | 0.00 | 2.08 | | 1.15 | 2.06 | 1.41 | 1.50 | 2.45 | 2.06 |
| Silviculture | 2.00 | 2.50 | 0.96 | 2.00 | 1.29 | | 1.63 | 0.58 | 2.06 | 0.82 | 1.41 | 1.26 |
| Forest | 0.50 | 0.00 | 2.31 | 0.00 | 2.22 | | 1.00 | 2.38 | 2.06 | 2.38 | 2.06 | 1.83 |
| Mining | 2.50 | 0.50 | 0.58 | 1.50 | 2.22 | | 1.00 | 1.15 | 0.82 | 1.73 | 0.00 | 0.00 |
| Urban | 0.00 | 0.50 | 0.00 | 0.50 | 0.00 | | 0.50 | 0.00 | 0.00 | 0.96 | 1.83 | 1.73 |
| Hydrography | 1.00 | 0.50 | 0.00 | 0.00 | 0.96 | | 1.00 | 1.89 | 2.45 | 1.91 | 0.00 | 0.96 |