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1 **ECONOMIC RISKS OF ENVIRONMENTAL SETBACKS IN BRAZIL'S**  
2 **IGUAÇU NATIONAL PARK**

3 VICTOR MATEUS PRASNIEWSKI<sup>1\*</sup>, NEUCIR SZINWELSKI<sup>2</sup>, CARLOS RODRIGO  
4 BROCARDO<sup>1</sup>, PHILIP MARTIN FEARNside<sup>3</sup>, THADEU SOBRAL-SOUZA<sup>4</sup>

5  
6 <sup>1</sup>Programa de Pós-graduação em Ecologia e Conservação da Biodiversidade. Universidade  
7 Federal da Fronteira Sul. Avenida Edmundo Gaievski, 1000, Rodovia BR-182 - Km 466 Cx  
8 Postal 253 Zona Rural, Realeza, Paraná, 85770-000, Brazil.

9 \*Corresponding author: victor.mateus.pras@gmail.com

10  
11 <sup>2</sup>Universidade Estadual do Oeste do Paraná. Rua Universitária 2069, Jardim Universitário,  
12 Cascavel, Paraná, CEP 85819-110, Brazil.

13  
14 <sup>3</sup>Instituto Nacional de Pesquisas da Amazônia (INPA), Av. 585 André Araújo, 2936, Manaus,  
15 Amazonas, CEP 69.067-375, Brazil.

16  
17 <sup>4</sup>Departamento de Botânica e Ecologia, Universidade Federal do Mato Grosso, Campus  
18 Cuiabá. Av. Fernando Corrêa da Costa, 2367, Bairro Boa Esperança, Cuiabá, Mato Grosso,  
19 CEP 78060-900, Brazil.

## 20 Abstract

21 Iguaçu National Park, a UNESCO World Heritage Site, faces threats from proposed  
 22 legislation aimed at downgrading its protection to allow reopening of the Caminho-do-Colono  
 23 road, which would fragment the Park. This study assesses the Park's importance in preserving  
 24 native vegetation and its economic significance via payments for environmental services  
 25 (ICMS-e). We evaluated different scenarios, demonstrating how these resources are vital for  
 26 certain municipalities. By comparing economic performance before and after the road's  
 27 closure, our findings reveal that, contrary to local beliefs, the closure did not negatively  
 28 impact the local economy. Additionally, these legislative bills are legally unfeasible and fail  
 29 to offer environmental or economic benefits, favoring small interest groups over the collective  
 30 good. This research highlights that the Caminho-do-Colono is not a viable path for municipal  
 31 development. Instead, maintaining the Park's integrity is crucial for both ecological  
 32 preservation and economic stability in the region. Our analysis underscores the broader  
 33 implications of environmental conservation efforts and the necessity of rejecting projects that  
 34 compromise protected areas. This study provides a comprehensive evaluation of the Park's  
 35 role, emphasizing the need for sustainable development that aligns with environmental and  
 36 community well-being.

37  
 38 **Keywords** PADDD; Atlantic Forest; Protected areas, Caminho-do-Colono, Environmental  
 39 services, Ecosystem services

## 42 Introduction

43 The Atlantic Forest has been almost destroyed by 500 years of human exploitation  
 44 (Dean 1995, Joly et al. 2014), and what remains of its original formation is heavily  
 45 fragmented into thousands of small and isolated forest patches (Ribeiro et al. 2009). Due to  
 46 these impacts, a significant portion of its biodiversity has been irrevocably lost, but the  
 47 biodiversity that persists makes the Atlantic Forest one of the world's five most important  
 48 biodiversity hotspots (Myers et al. 2000, Joly et al. 2014). The drastic reduction in forest  
 49 cover of the Atlantic Forest is largely due to logging and the establishment of agricultural  
 50 areas (Galindo-Leal & Câmara 2005). Most of what is left of the Atlantic Forest in Brazil is  
 51 concentrated in areas with steep slopes, where agriculture is difficult, such as the Serra do  
 52 Mar, Paranapiacaba, and the Mantiqueira areas (Tabarelli et al. 2010). The only exception in  
 53 Brazil, where a large Atlantic Forest remnant occurs in less rugged terrain, is *ParNa Iguaçu*  
 54 (Iguaçu National Park), created in 1939 around the iconic Iguaçu Falls, a UNESCO World  
 55 Heritage Site (UNESCO 2022), and one of the seven natural wonders of the world due to its  
 56 scenic beauty (N7W 2022). *ParNa Iguaçu*, along with protected and unprotected areas in the  
 57 province of Misiones (Argentina), form one of the largest remnant patches of Atlantic Forest,  
 58 with almost one million hectares (Ribeiro et al. 2009).

59 The scenic beauty of the Iguaçu Falls is an example of an ecosystem service that  
 60 natural ecosystems provide to humans free of charge (Tallis & Kareiva 2005). However,  
 61 *ParNa Iguaçu* represents much more than just its falls, with various other important  
 62 ecosystem services provided by its 185,000 ha. *ParNa Iguaçu* boasts a vast biodiversity: 619  
 63 known species of vascular plants (Trochez et al. 2017), 335 bird species (Straube et al. 2004),  
 64 102 mammals (Brocardo et al. 2019), 12 amphibians (ICMBio 2018), 48 reptiles (ICMBio  
 65 2018), and invertebrates including 89 species of butterflies (Fianco et al. 2022), 135 species of  
 66 Cerambycidae beetles (Barros et al. 2020), and over 800 known species of other invertebrates  
 67 (ICMBio 2018). All of these numbers are undoubtedly underestimates.

68 In Brazil the conservation and preservation of natural habitats and, consequently, the  
 69 maintenance of ecosystem services, are incentivized through payment for environmental

70 services by transferring financial resources from the state governments to the municipalities  
71 (counties). The *Imposto sobre Circulação de Mercadorias e Serviços* (ICMS, or Tax on  
72 Circulation of Goods and Services), is a state tax, the implementation of which is governed by  
73 Article 155 of the Federal Constitution (Brazil 1988). In the state of Paraná, 25% of the  
74 amount collected from this tax is transferred to municipalities according to a Municipality  
75 Participation Index, and state legislation stipulates that 5% of this transfer be allocated to  
76 municipalities that have water supply catchment areas for neighbouring municipalities,  
77 conservation units or Indigenous lands. This gave rise to the ICMS-e (ecological ICMS),  
78 which was pioneered by Paraná (Paraná 1991) and serves as a model now adopted by almost  
79 all Brazilian states. In 2021, Paraná transferred almost 478 million reais (~US\$ 93 million –  
80 conversion on 20 May 2024) to Paraná municipalities in ICMS-e, of which the 13  
81 municipalities bordering *ParNa Iguaçu* received 29 million reais due to the Park (IAT 2022).  
82 This amount can increase with the improvement or expansion of municipal conservation areas  
83 or can decrease due to factors such as the reduction, extinction, or recategorization of  
84 conservation units (Bernard et al. 2014). Thus, investment in the persistence of protected  
85 areas and water catchment areas is a way to ensure the maintenance of various ecosystem  
86 services, biodiversity, environmental health, human well-being, and the economic health of  
87 municipalities.

88 However, despite being iconic and environmentally and economically important,  
89 *ParNa Iguaçu* has been facing serious threats and pressures, including the processing of two  
90 bills directly affecting the Park that are advancing through committees in the National  
91 Congress: PL 7123/2010 (Maria 2019) and PL 984/2019 (Couto 2010), setting a precedent  
92 that may affect other conservation units (protected areas for biodiversity). Both bills propose  
93 changes to Law 9985/2000, which establishes the National System of Nature Conservation  
94 Units, or SNUC (Brazil 2000), to establish a new type of protected area, the ‘park-road’. This  
95 new type of protected area would be a ‘sustainable use’ conservation unit under the terms of  
96 article 14 of Law 9985/2000, reducing the current level of conservation and protection of  
97 *ParNa Iguaçu*. These bills propose the reopening of the Caminho-do-Colono road along a  
98 route through secondary forest with over 20 years of regeneration, where, prior to 2001, a  
99 road cut through the Park for 17.5 km between the municipalities of Serranópolis do Iguaçu  
100 and Capanema (Prasniewski et al. 2020).

101 Such proposals imply environmental damage from Park fragmentation, wildlife  
102 roadkill, and deforestation for road construction, as well as potentially increasing illegal  
103 activities within the Park (Prasniewski et al. 2022). It would also cause significant economic  
104 losses to the region (Ortiz 2009). A reduction in either the area of a conservation unit or its  
105 protection status would result in decreased transfers of ICMS-e to the affected municipalities,  
106 harming the region's development instead of improving it as the local population generally  
107 believes. Especially in the municipalities of Serranópolis do Iguaçu and Capanema, residents  
108 have often been influenced by political leaders who argue in favour of opening the Caminho-  
109 do-Colono road using a discourse that has been characterized as fallacious and simplistic  
110 (Garcia and Baptiston 2014, Kropf and Eleutério 2015). In contrast, a national view is against  
111 the road opening; in the poll conducted by the Chamber of Deputies, where 95% of those  
112 interviewed were against opening the road (Câmara dos Deputados 2023). Nevertheless, Bill  
113 7123/2010 was approved by the Chamber of Deputies (G1 2013) and is under review in the  
114 Federal Senate, and Bill 984/2019 had its urgency regime approved by 315 votes in favor  
115 versus 180 against (G1 2021) and is awaiting consideration by the plenary of the Chamber.

116 The present study investigates the economic and environmental implications of  
117 reopening the Caminho-do-Colono road through *ParNa Iguaçu*. We assessed the importance  
118 of *ParNa Iguaçu* for biodiversity conservation and the economy of the municipalities in the  
119 region through payment for environmental services, as well as the potential economic impacts

120 of reopening the Caminho-do-Colono road. The main objective is to assess the impact of  
121 proposed legislative changes on the conservation of the Park and its economic importance to  
122 local municipalities through the ICMS-e. Despite the recognized importance of protected  
123 areas, there is limited empirical evidence on the economic impacts of opening or closing roads  
124 in these areas, particularly in the context of the Atlantic Forest. We evaluated the Park's  
125 contribution to maintaining native vegetation cover in the region, testing the hypothesis that  
126 outside its boundaries, the amount of native forest decreased significantly between 1985 and  
127 2020 due to deforestation, while inside the Park, the amount of forest remained stable. We  
128 estimated the economic importance of *ParNa Iguaçu* for the municipalities either overlapping  
129 or neighboring the Park, testing the hypothesis that ICMS-e significantly contributes to the  
130 economic performance of these municipalities and that the reopening of the Caminho-do-  
131 Colono road will have negative impacts on this performance. Finally, we calculated whether  
132 the economic performance of the municipalities was affected by the closure of the Caminho-  
133 do-Colono road, testing the hypothesis that the road closure did not affect the economic  
134 performance of the municipalities or the region. Understanding the consequences of such  
135 legislative actions is crucial for informing policy decisions that balance conservation and  
136 development goals in biodiversity hotspots like the Atlantic Forest.

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## 138 **Materials and methods**

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### *Study area*

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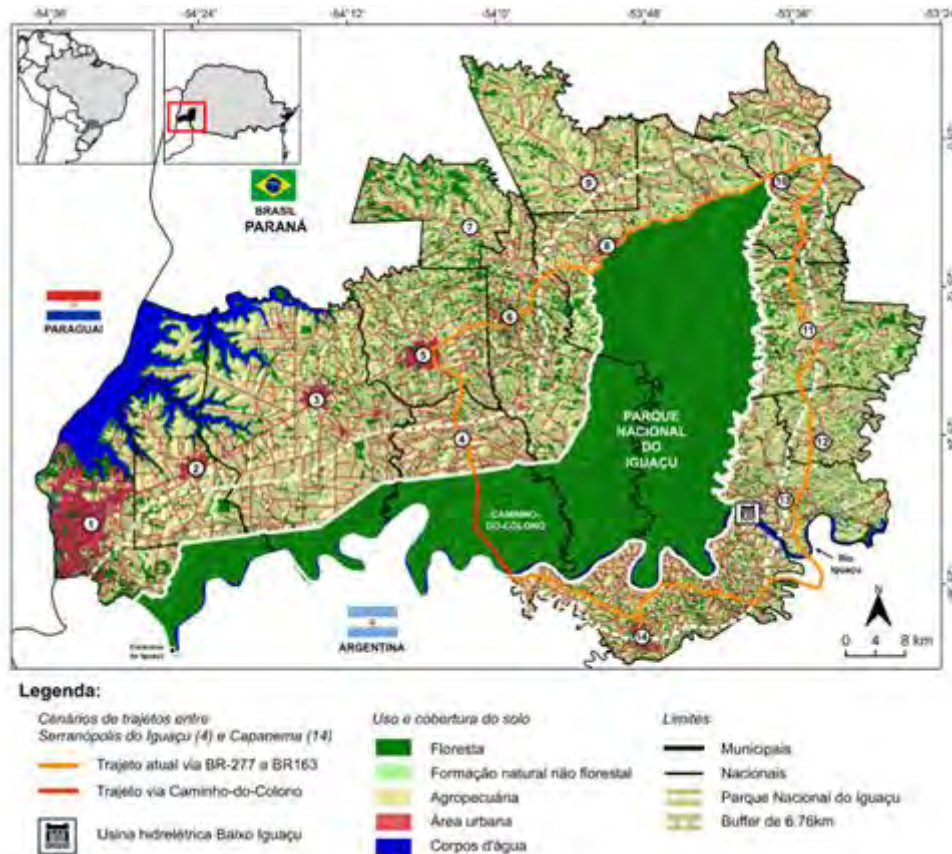
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*ParNa Iguaçu* was created by Decree 1035/1939 and expanded by Decrees 6506/1944 and 6587/1944, with current territorial boundaries and area (185,262.00 ha) defined by Decree 86,676/1981, which excluded 1400 ha in the northern portion and included the Iguaçu River as part of the Park (Brazil 1939, 1944a, b, 1981). *ParNa Iguaçu* is almost completely surrounded by an agricultural matrix of soybeans, corn, and wheat (Figure 1), and has two important routes for transportation of people and goods: the BR-277 and BR-163 highways. These highways would continue to be the transportation routes for agricultural commodities from the municipalities bordering the Park, even if the Caminho-do-Colono road were to be reconstructed, as the proposed road would not shorten the route to export ports. Outside of the Park, the few forest fragments in the region are scattered and small. *ParNa Iguaçu* has a subtropical climate (Cfa in the Köppen classification), with an average annual temperature of 21°C and 1807 mm of rainfall at the lowest altitude of the Park (minimum 140 m in Foz do Iguaçu) and an average temperature of 19.9°C and 1933 mm of precipitation at the highest altitude (750 m, in Céu Azul) (Alvares et al. 2013). The topography is flatter in the western part of the Park, with gently sloping hills, while the eastern and northern parts have more rugged terrain (Salamuni et al. 2022). The Park is located in the lower Iguaçu basin, and its drainage network is composed of tributaries on the right bank of this river. The Iguaçu River has six hydroelectric dams, the most recent of which is only 500 m from the eastern border of the Park, heavily impacting the water regime. Six municipalities have territory within the Park boundaries (Foz do Iguaçu, São Miguel do Iguaçu, Serranópolis do Iguaçu, Matelândia, Céu Azul, and Capanema), in addition to eight municipalities neighbouring the Park (Santa Terezinha de Itaipu, Medianeira, Ramilândia, Santa Tereza do Oeste, Vera Cruz do Oeste, Lindoeste, Santa Lúcia, Capitão Leônidas Marques) (Figure 1). The municipality of Ramilândia was not included in the analyses of ICMS-e and economic performance because it does not receive any ICMS-e resources from *ParNa Iguaçu*.



167  
168 **Figure 1.** Map of the study region covering *ParNa Iguazu* and its neighbouring municipalities: 1) Foz do  
169 Iguazu; 2) Santa Terezinha do Itaipu; 3) São Miguel do Iguazu; 4) Serranópolis do Iguazu; 5) Medianeira; 6)  
170 Matelândia; 7) Ramilândia; 8) Céu Azul; 9) Vera Cruz do Oeste; 10) Santa Tereza do Oeste; 11) Lindoeste; 12)  
171 Santa Lúcia; 13) Capitão Leônidas das Marques; 14) Capanema.

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#### *Importance of ParNa Iguazu for maintaining native vegetation cover*

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between these terms, as predictor variables (x-axis).

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#### *Importance of ParNa Iguazu for the economy of the municipalities*

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To test the hypothesis that ICMS-e significantly contributes to the economic performance of municipalities within and adjacent to *ParNa Iguazu*, we used economic data from the Instituto Paranaense de Desenvolvimento Econômico e Social (IPARDES) (IPARDES 2023). We employed annual ICMS-e data, disbursed to municipalities

196 (Capanema, Céu Azul, Foz do Iguaçu, Matelândia, São Miguel do Iguaçu, Serranópolis do  
 197 Iguaçu, Santa Lúcia, Capitão Leônidas Marques, Lindoeste, Vera Cruz do Oeste, Medianeira),  
 198 along with municipal revenue and expenditure data for each of these municipalities. The  
 199 ICMS-e data used in this stage are specifically related to values derived from the presence of  
 200 *ParNa Iguaçu*, considering the Park's own area plus any surrounding areas, such as Riparian  
 201 Forests, Permanent Preservation Areas, and Legal Reserves (if applicable), as per Annex III  
 202 of the Instituto Ambiental do Paraná (IAP) Directive (1998). This exclusion removes ICMS-e  
 203 values originating from other conservation units. The metric used to represent the economic  
 204 performance of the municipalities was the 'Liquidity Index' (LI), estimated as the ratio of  
 205 revenues to expenses of the municipalities, where values greater than 1 indicate a surplus and  
 206 values less than one indicate a deficit in public accounts. To obtain the LI values with and  
 207 without ICMS-e, we subtracted the ICMS-e value from the revenue of each municipality for  
 208 each year from 1998 to 2021 (Table S1). The period from 2012 to 2014 was not considered  
 209 due to a lack of available data on the disbursement from each conservation unit to each  
 210 municipality. With these observations, we conducted a Wilcoxon test for each municipality,  
 211 adjusting LI as the response variable (y-axis), and revenues with ICMS-e and without ICMS-e  
 212 as predictor variables (x-axis).

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#### 214 *Impacts of reopening Caminho-do-Colono on municipal economies*

215 To test the hypothesis that the reopening of the Caminho-do-Colono road might  
 216 impact the transfer of ICMS-e to municipalities due to the reduction in conservation quality  
 217 scores of *ParNa Iguaçu* in the ICMS-e calculation table, we estimated the potential impacts of  
 218 reopening this road on these scores. At this stage, we only used ICMS-e values from *ParNa*  
 219 *Iguaçu*, disregarding values from surrounding areas, because only the area of *ParNa Iguaçu*  
 220 would be affected by the reopening of the Caminho-do-Colono road. The biodiversity ICMS-  
 221 e for a conservation unit (CU) in a given municipality is calculated considering the following  
 222 parameters: i) the municipality's area; ii) the area of the conservation unit within the  
 223 municipality; iii) a basic conservation factor (*FCb*), defined for federally-owned units as 0.7 if  
 224 the unit was created after the municipality's emancipation and 0.35 if before; iv) the variation  
 225 of the current year's conservation unit quality score compared to the previous year ( $\Delta Quc$ ),  
 226 which cannot exceed 0.55 for federally-owned CUs, calculated based on an evaluation table  
 227 covering various factors such as threats and aggression (item V) (IAT 2020); v) weighted  
 228 score where a value of 1 represents federally-owned CUs, values below this represent lower  
 229 hierarchies of conservation units (e.g. state, municipal CUs). Details and examples of ICMS-e  
 230 calculation formulas are presented in Appendix S1. The result of the change in  $\Delta Quc$  can be at  
 231 most an increase or loss of 45% of the transfer regarding the CU, either by an increase or a  
 232 decrease in the quality score in the calculation table. The reopening of the Caminho-do-  
 233 Colono road may directly affect item V (Threats and aggression to the CU). However,  
 234 projecting the exact value of the score to be reduced if the road is reopened is challenging  
 235 because it depends on the evaluation by the responsible agency - potentially even being  
 236 completely removed, as per article 18 of IAP Ordinance 263 of 28 December 1998. Thus, for  
 237 municipalities where the withdrawal of ICMS-e would significantly impact the LI, we  
 238 estimate the loss of score at different values (0.55, 0.25, and 0.1), resulting in different  
 239 percentages of ICMS-e loss (45%, 25%, and 10%), and then subtracted this lost ICMS-e from  
 240 the revenue for each year and updated the LI values. With these data, we conducted Wilcoxon  
 241 tests for each municipality, adjusting LI as the response variable (y-axis), and the loss  
 242 percentage groups (45%, 25%, and 10%) as predictor variables (x-axis), comparing each loss  
 243 group with the reference group in which there is no ICMS-e loss.

244 According to item II of article 16 of IAP Ordinance 263 of December 28, 1998, part of  
 245 the area of a CU may be considered to have unsatisfactory physical quality due to insufficient

246 characteristics for its being fully identified with the management category of the respective  
 247 area. This may result in subtracting the area of the CU considered within the municipality.  
 248 Thus, we estimated the LI with the reduced ICMS-e by the percentage loss of quality score  
 249 (45%, 25%, and 10%) due to the reopening of the Caminho-do-Colono road in different  
 250 scenarios of area loss exclusively from *ParNa Iguaçu*, without considering surrounding areas,  
 251 in the municipality of Serranópolis do Iguaçu: a) without loss in the calculation area; b) loss  
 252 of the Caminho-do-Colono road route area considering a strip of 12 m by 17.5 km (-25.6 ha);  
 253 c) loss of the route area plus a 100-m buffer (-200.6 ha); d) loss of the route area plus a 1.5-  
 254 km buffer - regarding the edge effect on vegetation biomass reported by Chaplin-Kramer et al.  
 255 (2015) (-2650.6 ha); e) loss of the route area plus the area susceptible to increased illegal  
 256 activities (Prasniewski et al. 2022) (-10,025.6 ha). Since the CU area used in the calculation  
 257 and the  $\Delta Qua$  for all years are not available, we first calculated all scenarios with the data  
 258 from 2021, estimated a percentage change in each scenario, and applied this percentage  
 259 reduction for the remaining years. With these data, we conducted Wilcoxon tests for each  
 260 municipality, with LI as the response variable (y-axis), and the percentage loss groups (45%,  
 261 25%, and 10%) as predictor variables (x-axis), comparing each loss group with the reference  
 262 group without an increase in ICMS-e.

263

264 *The economic performance of municipalities before and after the closure of Caminho-*  
 265 *do-Colono*

266 To test the hypothesis that the closure of the Caminho-do-Colono road did not affect  
 267 the economic performance of municipalities, we used historical economic data (1980 - 2021)  
 268 on municipal revenues and expenses available from IPARDES (IPARDES 2023, Table S2).  
 269 We conducted a Wilcoxon test for each municipality, where the LI metric described above  
 270 was the response variable (y-axis), and the period when the road was open (1980 - 2000) and  
 271 the period since the closure (2001 - 2022) were the explanatory variables (x-axis). Finally, we  
 272 evaluated the effect on the regional economy, considering the sum of revenues and expenses  
 273 from all municipalities, with and without ICMS-e and before and after the closure of the  
 274 Caminho-do-Colono road, also using the Wilcoxon test. To ensure the robustness of the  
 275 results, given that the period from 1980 to 2022 was marked by some economic recessions in  
 276 Brazil, we tested for correlation between municipal LIs and the variation in the Brazilian GDP  
 277 (Gross Domestic Product) during this period – available in the Time Series Management  
 278 System of the Central Bank (BCB 2023). However, no significant correlation was found  
 279 (Table S3).

280

## 281 **Results**

282

283 *Importance of ParNa Iguaçu for maintaining native vegetation cover*

284 Due to deforestation, the amount of native forest outside the Park boundaries significantly  
 285 decreased between 1985 and 2020, while within the Park, the amount of native forest  
 286 remained virtually unchanged ( $F = 172.35$ ;  $p < 0.001$ ; Figure S1). Over the 31-year period,  
 287 *ParNa Iguaçu* retained 95.6% of its area covered by native vegetation. Conversely, the native  
 288 vegetation cover outside the Park, which was 13.18% (20,468.65 ha) in 1988, decreased to  
 289 9.59% (14,884.32 ha) during the evaluated period. The area outside the Park lost 27.28% or  
 290 5,584.33 ha of its native vegetation over the 31 years.

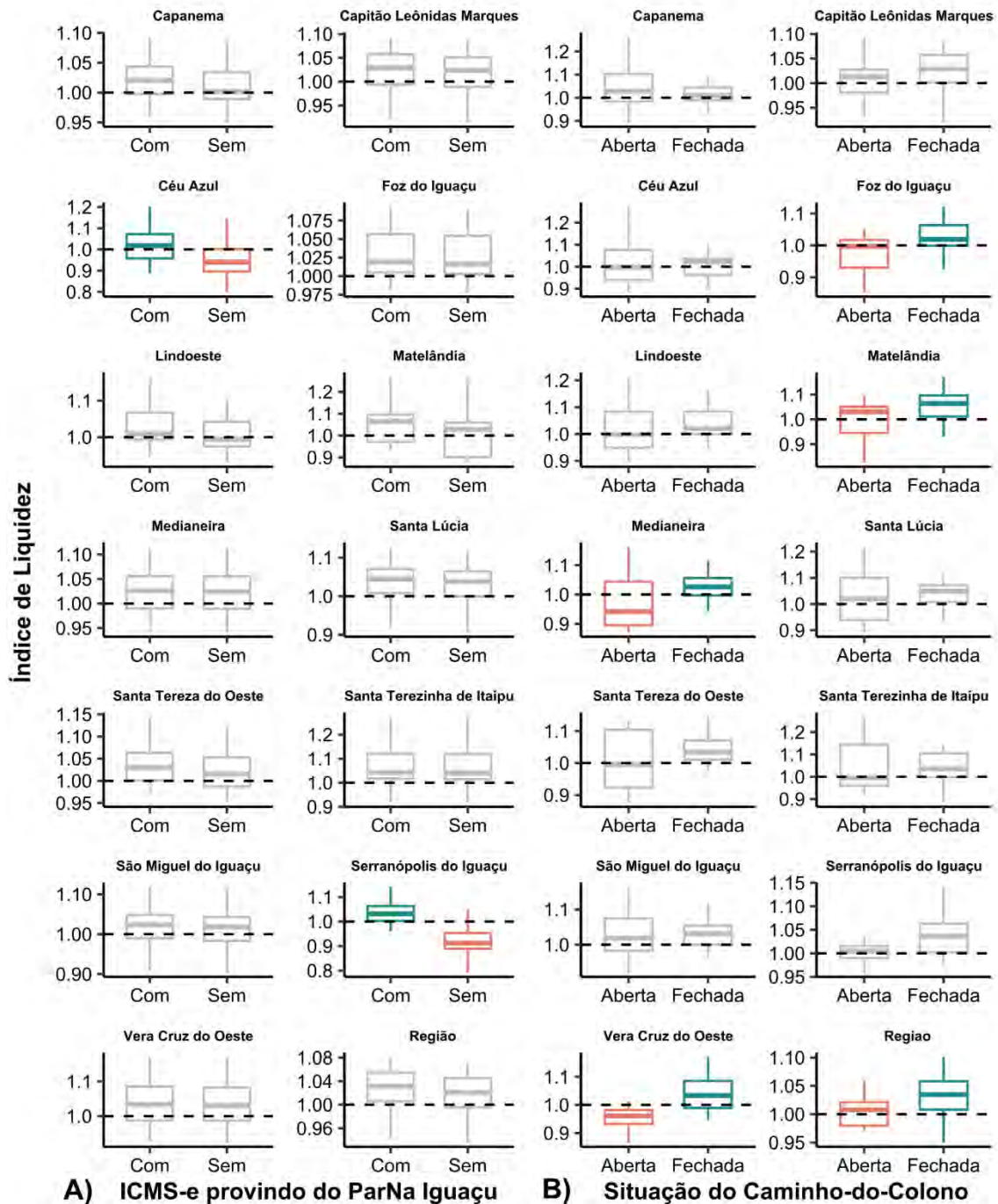
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292 *Importance of ParNa Iguaçu for the economy of the municipalities*

293 Considering the 13 municipalities either overlapping or neighbouring *ParNa Iguaçu*,  
 294 the ICMS-e generated by this conservation unit significantly contributes to the LI of the  
 295 municipalities of Serranópolis do Iguaçu ( $W = 388$ ;  $p < 0.001$ ) and Céu Azul ( $W = 293$ ;  $p =$



296 0.011; Figure 2A and Table 1). The withdrawal or loss of ICMS-e resources transferred by the  
 297 state of Paraná to these municipalities would generate a deficit in public accounts, with an LI  
 298 reduction from 1.03 to 0.91 for the municipality of Serranópolis do Iguaçu, and from 1.02 to  
 299 0.94 for Céu Azul (Figure 3A).  
 300



301 **Figure 2.** Liquidity Index (LI) of the municipalities overlapping or neighbouring *ParNa Iguaçu*. A) Impact of  
 302 the withdrawal of IMCS-e on the LI of municipalities. B) Economic performance of the municipalities and the  
 303 region in the period when the road was open (1980 - 2001) and since its closure (2001 - 2022). Grey boxplots  
 304 represent municipalities whose liquidity index did not show significant differences.  
 305

306  
 307 **Table 1.** Wilcoxon test results for scenarios with and without ICMS-e and periods when Caminho-do-Colono  
 308 was open (1980 - 2001) and since its closure (2001 - 2022). The one-tailed test on the right indicates that the  
 309 Liquidity Index was higher when the Camino-do-Colono was open, while the left indicates the opposite. Values  
 310 in bold indicate statistically significant values.

Municipality	ICMS-e		Before and after closing the Caminho-do-Colono road			
	W	p-value	W	p value		
				Unicaudal (right)	Bicaudal	Unicaudal (left)
Capanema	255	0.397	241	0.215	0.430	0.792
Capitão Leônidas Marques	243	0.584	160	0.937	0.132	0.066
Céu Azul	293	<b>0.011</b>	211	0.598	0.823	0.411
Foz do Iguaçu	238	0.672	125	0.993	<b>0.016</b>	<b>0.008</b>
Lindoeste	267	0.250	94	0.806	0.411	0.205
Matelândia	294	0.066	142	0.977	<b>0.049</b>	<b>0.025</b>
Medianeira	233	0.765	136	0.984	<b>0.035</b>	<b>0.017</b>
Santa Lúcia	246	0.533	73	0.709	0.615	0.308
Santa Tereza do Oeste	219	0.270	78	0.836	0.350	0.175
Santa Terezinha de Itaipu	234	0.746	165	0.753	0.512	0.256
São Miguel do Iguaçu	243	0.584	200	0.700	0.618	0.309
Serranópolis do Iguaçu	388	<b>&lt;0.001</b>	24	0.911	0.203	0.102
Vera Cruz do Oeste	234	0.746	67	1.000	<b>&lt;0.001</b>	<b>&lt;0.001</b>
Region as a whole	256	0.382	137	0.983	<b>0.036</b>	<b>0.018</b>

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*Economic performance of municipalities before and after closure of Caminho-do-Colono*

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*Impacts of reopening Caminho-do-Colono on the economic performance of municipalities*

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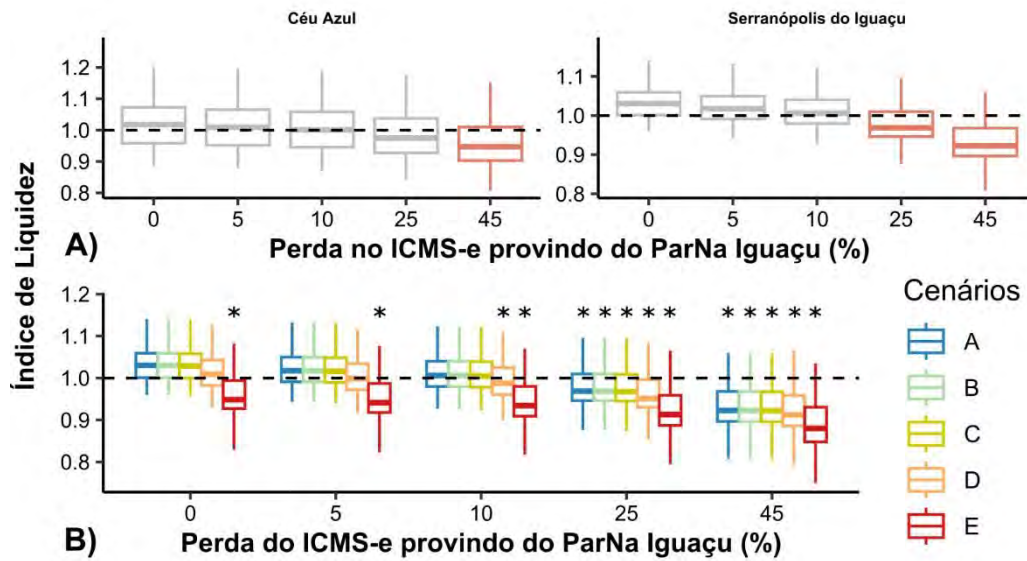
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If the quality score of the CU is impacted by the reopening of the Caminho-do-Colono road, a 25% reduction in transfer would affect the LI of Serranópolis do Iguaçu municipality (W = 310; p = 0.002), and a 45% reduction would negatively impact the LI of Céu Azul municipality (W = 287; p = 0.018; Figure 3A, Table 2). Additionally, if the satisfactory area for ICMS-e calculation is altered due to the road reopening in Serranópolis do Iguaçu municipality, only the reduction in scenario E (-10,025.6 ha) would have a significant impact on the LI, reducing it from 1.03 to 0.95 (W = 326; p < 0.001; Figure 3B, Table 3). This worsens when combined with the 45% reduction, for example potentially reducing the LI from 1.03 to 0.88 (W = 370; p < 0.001; Fig 3B; Table 3).



336  
 337 **Figure 3.** Possible reduction in ICMS-e and its impact on the LI due to the reopening of the Caminho-do-Colono  
 338 road. A) Percentage reduction in ICMS-e due to reduction in the conservation quality scores of *ParNa Iguaçu*,  
 339 which can reach a maximum loss of 45% (boxplots in grey represent the percentages that did not show  
 340 significant differences from the LI). B) Percentage reduction of ICMS-e in the municipality of Serranópolis do  
 341 Iguaçu due to a reduction in the conservation quality scores of Iguaçu National Park added to a reduction in the  
 342 area of *ParNa Iguaçu* used in the calculation of ICMS-e, in the following scenarios: a – No loss in the  
 343 calculation area; b – Loss of the area of the Caminho-do-Colono road; c – Loss of the road area plus a 100-m  
 344 buffer; d – Loss of the road area plus a buffer of 1.5 km of edge effect on plant biomass (Chaplin-Kramer et al.  
 345 2019); and – Loss of the road area plus the area where illegal activities are likely to increase (Prasnievski et al.  
 346 2022).  
 347

348 **Table 2.** Wilcoxon test results for scenarios with percentage loss of ICMS-e due to reductions in the  
 349 conservation quality score of Iguaçu National Park with the reopening of Caminho-do-Colono. Values in bold  
 350 indicate statistically significant values.

Municipality	Loss of ICMS-e	W	p-value
Céu Azul	<b>45%</b>	287	<b>0.018</b>
	25%	249	0.192
	10%	227	0.478
	5%	219	0.621
Serranópolis do Iguaçu	<b>45%</b>	343	<b>0.000</b>
	<b>25%</b>	310	<b>0.002</b>
	10%	252	0.165
	5%	232	0.398

351  
 352  
 353 **Table 3.** Wilcoxon test results for scenarios with percentage loss of ICMS-e and reduction of the satisfactory  
 354 area in the calculation of ICMS-e due to the reopening of Caminho-do-Colono. Values in bold indicate  
 355 statistically significant values.

Loss of ICMS-e	Scenario	W	p-value
45%	A	343	<b>&lt;0.001</b>
	B	343	<b>&lt;0.001</b>
	C	343	<b>&lt;0.001</b>
	D	348	<b>&lt;0.001</b>
	E	370	<b>&lt;0.001</b>
25%	A	310	0.0024

	B	310	0.0024
	C	311	0.0022
	D	324	<0.001
	E	348	<0.001
10%	A	252	0.1653
	B	252	0.1653
	C	254	0.1493
	D	288	0.0167
	E	336	<0.001
5%	A	232	0.3983
	B	232	0.3983
	C	235	0.3547
	D	266	0.0763
	E	329	<0.001
0%	B	210	0.7994
	C	211	0.7788
	D	246	0.2211
	E	326	<0.001

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### Discussion

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The Park ensures the existence and persistence of forest cover over time within its territory, while native forest in its surrounding areas continues to diminish. The guarantees continuity of ecosystem processes and services that are not generated to the same extent in deforested areas. Locally, the maintenance of natural forests and water sources is rewarded through financial transfers by state governments, especially by Paraná, the pioneering state in implementing the ICMS-e. Loss of this compensation could negatively affect the financial health of these municipalities. Although the values of ICMS-e do not affect the Liquidity Index (LI) of the region as a whole, possibly because larger municipalities with diversified revenues do not depend on these values, smaller municipalities rely on this resource to maintain their financial balance. This demonstrates the importance of the Park not only for biodiversity and ecosystem services but also, although little recognized, for local economies.

Reduction of the remaining forest to the few small fragments in the landscape surrounding *ParNa Iguaçu* is a result of the historical and cultural context of land occupation from 1900 to 1990, which expanded from the coast to the western part of the state of Paraná, in the so-called ‘march to the west’ (Gubert-Filho 2010). This colonization expansion reached the western part of the state around 1920, and many families descended from European immigrants, mainly from the states of Santa Catarina and Rio Grande do Sul, settled in the *ParNa Iguaçu* region, subsidized by the colonization companies and real estate agencies of the time, many of which were also logging companies. The suppression of native forests occurred primarily due to the expansion of the timber trade, mainly of araucaria (*Araucaria angustifolia*) and peroba (*Aspidosperma polyneuron*), and, subsequently, the progressive conversion, mainly in the 1950s, of these areas into small-scale agriculture and large areas of pasture, a transformation that continued until the mid-1990s (Priori et al. 2012). Finally, in the last 20 years, these pastures have been converted to soybean and corn monocultures (MAPBIOMAS 2022). The creation of *ParNa Iguaçu* in 1939 allowed for the maintenance of native forest cover, protecting it from extractive territorial expansion throughout this period, marking the contrast observed in land cover around the Park. This reinforces the effectiveness

385 of establishing conservation units (especially full-protection conservation units) as a strong  
386 public policy for environmental conservation and preservation (Brocardo et al. 2022).

387 Anthropogenic disturbances can cause a reduction in carbon stocks in forests, mainly  
388 through reduction and fragmentation, which lead to increased forest edges and allow for  
389 greater wind action, higher temperature, and lower humidity. These factors lead to increased  
390 plant mortality rates (Laurance & Curran 2008), resulting in a reduction in carbon stocks  
391 (Chaplin-Kramer et al. 2015). Thus, the deforestation and environmental degradation that  
392 would be caused by the reopening of the Caminho-do-Colono would directly affect the carbon  
393 stock in an area of 26.5 ha (17.5 km × 12 m). Indirectly, this impact would be much greater,  
394 due to the edge effect (Chaplin-Kramer et al. 2015). The reopening of the Caminho-do-  
395 Colono has the potential to compromise the ability of *ParNa Iguaçu* to maintain viable  
396 populations of various species, increasing the frequency of illegal activities such as hunting,  
397 fishing, and extraction of palm hearts (*Euterpe edulis*) in an area of up to 10,000 ha  
398 (Prasniowski et al. 2022). Additionally, a road represents a severe risk of collisions for species  
399 such as the jaguar (*Panthera onca*) (Brocardo et al. 2019), similar to what happens in the  
400 Morro do Diabo State Park, where in less than a week, two individuals of this species were  
401 run over on the highway that cuts through the Park (G1 2023).

402 The environmental degradation that could be caused by reopening the Caminho-do-  
403 Colono would also have direct impacts on the economies of municipalities overlapping or  
404 neighbouring *ParNa Iguaçu* because for some municipalities the ICMS-e values received for  
405 the conservation of forest environments have significant economic importance. Our results  
406 show that the ICMS-e collected is a significant contribution to the revenue of the  
407 municipalities of Céu Azul and Serranópolis do Iguaçu, allowing for a surplus in these  
408 municipalities. Losses due to the road would be expected because the percentage that each  
409 municipality receives in ICMS-e transfer is based on how much it protects and conserves the  
410 Park. The municipalities of Serranópolis do Iguaçu and Céu Azul would have their economic  
411 balance affected if there were a reduction in the transfer of this resource by 25% and 45%,  
412 respectively, solely due to the reduction in environmental quality scores. The municipality of  
413 Serranópolis do Iguaçu is the most dependent on ICMS-e from *ParNa Iguaçu* because the  
414 Caminho-do-Colono route is within its territorial limits; the reopening of this road could  
415 result in a financial deficit of up to 12% per year.

416 Contrary to what is argued by supporters of reopening the Caminho-do-Colono, the  
417 financial balances of the municipalities, especially Capanema and Serranópolis do Iguaçu,  
418 were not higher when the road was in operation. Far from it, some municipalities showed a  
419 surplus in the period when the road remained closed, such as Matelândia and Medianeira  
420 (from which Serranópolis do Iguaçu was emancipated in 1997). This demonstrates, for  
421 example, that these municipalities, even though they are on the route of the Caminho-do-  
422 Colono, developed without needing this environmental setback, which also occurred when  
423 analyzing the economy of all municipalities together. Regional factors that undoubtedly  
424 influenced this development include increased agricultural production, industrialization, and  
425 tertiary services; relevant national factors include increased economic development after the  
426 mid-2000s (Reolon 2007). The economic dependence on this road is therefore a fallacious  
427 argument (Kropf & Eleutério 2015), with municipalities satisfactorily overcoming the absence  
428 of this route.

429 Reopening the Caminho-do-Colono would shorten (for a few) the distance between  
430 the municipalities of Serranópolis do Iguaçu and Capanema, although this shortcut would not  
431 serve to shorten the transport route for major agricultural products, such as soybeans. The  
432 reopening of the road would intensify various environmental problems that impact the  
433 collective and the revenues of the municipalities. Furthermore, the reopening of this road  
434 would deprive the Park of its role in maintaining native vegetation in the western and

435 southwestern portions of Paraná, where human occupation has left a large trail of  
436 environmental degradation. Finally, the present study demonstrates the possible negative  
437 financially impacts on nearby municipalities if this road were to be opened, and it dismantles  
438 the argument that the region would prosper with this road, an argument that is not supported  
439 by history.

440 The fallacious nature of political discourse claiming that Bills 7123/2010 and  
441 984/2019, which propose reopening the Caminho-do-Colono, are needed for the economies of  
442 municipalities near the Park is contradicted both by the expected losses of revenue to these  
443 municipalities from ICMS-e and by the fact that the economic performance of these  
444 municipalities was not negatively affected by the closure of the road in 2001. These results  
445 add to other studies that show the environmental setback of these proposals (Ortiz 2009,  
446 Prasniewski et al. 2020, 2022). The Caminho-do-Colono is being used by politicians as an  
447 opportunity to exploit personal sentiments to obtain votes and to favor small groups in  
448 detriment to the collective interest. Therefore, future studies and efforts should focus  
449 primarily on the sustainable use of the areas neighbouring *ParNa Iguaçu*. It is essential to  
450 document the benefits that municipalities can obtain from the expansion of protected areas,  
451 both in revenue and in ecosystem services associated with these natural regions. Instead of  
452 reducing or degrading the remaining natural vegetation, we should expand public policies,  
453 such as the ICMS-e, that encourage the creation of natural areas,. This would strengthen local  
454 and regional efforts to achieve global goals, such as Target 3 of the Kunming-Montreal  
455 Global Biodiversity Framework, which aims to conserve 30% of terrestrial and marine habitat  
456 by 2030.

457

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471

#### 472 **Conflict of interest**

473 None

474

#### 475 **Ethical standards**

476 Our study does not involve humans or animals and is in accordance with national, local and  
477 institutional laws and requirements.

478

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661

1 **Supplementary material**

2  
3 **Title: Brazil's Iguaçu National Park: Economic risks of proposed road construction and**  
4 **downgrading**

5  
6 **ICMS-e transfer calculations, as established in IAP Ordinance 263/98 and other**  
7 **standards.**

8  
9 *a. Basic Biodiversity Conservation Coefficient (CCB)*

10  
11 This is the ratio between the surface of the conservation unit contained within the  
12 territory of a given municipality ( $Auc$ ), by the total surface of the respective  
13 municipality ( $Am$ ), maintaining a unit of measurement, corrected by a Conservation  
14 Factor ( $Fc$  - Annex III of IAP Ordinance 263/98), defined according to the  
15 Management Category.

$$16 \quad CCB = \frac{Auc}{Am} \cdot Fc$$

17  
18 *b. Biodiversity Conservation Coefficient by Interface (CCBI)*

19  
20 This is the weighting of the CCB that is subject to change depending on the quality  
21 level of the conservation unit (or part) incident on the municipal territory, determined  
22 by the variation in conservation quality scores based on the annual application of an  
23 evaluation table o ( $\Delta Qua$ ) and weighted by a weight ( $P$ ) equivalent to the conservation  
24 unit's management hierarchy (municipal, state and federal) (parameters defined in  
25 Annex III of IAP Ordinance 126/96 ).

$$26 \quad CCB I = [CCB + (CCB \cdot \Delta Qua)] \cdot P$$

27  
28 *c. Environmental Index by Biodiversity (AI)*

29  
30 This is the ratio between the sum of the CCBI of all conservation units in the  
31 municipality (CCBM), by the sum of the CCBI calculated for all municipalities in the  
32 State (CCBE), converted to percentages and corrected by 1/2, to correspond to fifty  
33 percent of the total resources to be passed on to the municipalities.  
34  
35

$$36 \quad IA = 0.5 \cdot \frac{CCBM}{CCBE} \cdot 100\%$$

37  
38 *d. ICMS-e transfer*

39  
40 This is the IA multiplied by the value of the ICMS-e in reais (R\$) in a given year.  
41

$$42 \quad ICMS_e = \frac{IA(\%) \cdot repasse(R\$)}{100\%}$$

43  
44 *Note:* to obtain the transfer of ICMS-e providing only one conservation unit, it is  
45 enough to consider only the conservation unit interest in the municipality in the calculation of  
46 the IA instead of the sum of all conservation units.  
47

48 **Example of ICMS-e calculation.**

49

50 Considering, as an example, the Iguaçu National Park in the municipality of Céu Azul  
51 in the year 2021, we have the following parameters:

52

53 i) Area of Iguaçu National Park within the municipality of Céu Azul ( $Auc$ ) = 85,366.03

54 ii) Municipality area ( $Am$ ) = 117,659.78

55 iii) Conservation factor ( $Fc$ ) = 0.35 (reference values for National Parks created before the emancipation  
56 of the municipality – according to Annex III of IAP Ordinance 263/98)

57 iv) Variation in the conservation quality of the conservation unit ( $Qua$ ) = 0.31

58 v) Weight equivalent to the conservation unit's management hierarchy ( $P$ ) = 1 (for federal conservation  
59 units)

60 vi) Sum of the Conservation Coefficient per Interphase for the entire state ( $CCBE$ ) = 9.430

61 v) ICMS-e transfer = R\$ 477,985,067.96

62

$$63 \quad CCB = \frac{85366,03}{117659,78} \cdot 0,35 = 0,254$$

64

$$65 \quad CCBI = [0,254 + (0,254 \cdot 0,31)] \cdot 1 = 0,333$$

66

$$67 \quad IA = 0,5 \cdot \frac{0,333}{9,430406559} \cdot 100\% = 0,176980704$$

68

$$69 \quad ICMS_e = \frac{1,763746 \cdot R\$477,985,067,96}{100\%} = R\$ 8,439,139,00$$

70

71 Thus, the value transferred from ICMS-e referring to the ParNa Iguaçu to the municipality of Céu Azul  
72 in the year 2022 was R\$ 8,439,139.00.

## Supplementary material

Title: **Brazil's Iguazu National Park: Economic risks of proposed road construction and downgrading**

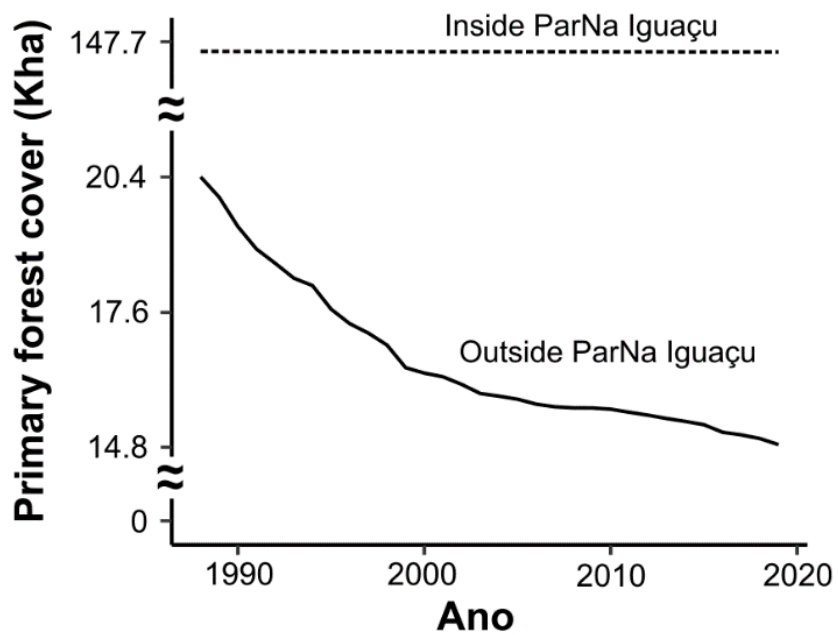


Figure S1. Primary forest cover outside and inside Iguazu National Park from 1987 to 2021.

1 **Supplementary material**

2

3 **Title: Brazil's Iguazu National Park: Economic risks of proposed road construction and**  
4 **downgrading**

5

6 **Summary of economic data used to the statistical analysis.**

7

8 **Table S1.** Years of municipal revenue and expenditure data from the Instituto de Água e Terra (IAT) used to  
9 assess the importance of the ecological ICMS from the Iguazu National Park for the economic performance of  
10 the municipalities. Source: <https://www.iat.pr.gov.br/Pagina/ICMS-Ecologico-por-Biodiversidade>

11

Municipalities	Years with available observations	Nº of samples
Capanema	1998 - 2011, 2015 - 2021	20
Capitão Leônidas Marques	1998 - 2011, 2015 - 2021	20
Céu Azul	1998 - 2011, 2015 - 2021	20
Foz do Iguaçu	1998 - 2011, 2015 - 2021	20
Lindoeste	1998 - 2011, 2015 - 2021	20
Matelândia	1998 - 2011, 2015 - 2021	20
Medianeira	1998-2004, 2006 - 2011, 2015-2021	19
Santa Lúcia	1998 - 2011, 2015-2021	20
Santa Tereza do Oeste	1998-2001,2003 - 2011, 2015-2021	19
Santa Terezinha de Itaipu	1998 - 2011, 2015-2021	20
Serranópolis do Iguaçu	1998 - 2011, 2015-2021	20
São Miguel do Iguaçu	1998 - 2011, 2015-2021	20
Vera Cruz do Oeste	1998 - 2011, 2015-2021	20

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